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DECOMPOSITION OF ROCKS IN BRAZIL.

UNDER the above title Dr. J. C. Branner[1] has recently brought together an extensive series of observations scattered through the literature relating to Brazil, with many original notes of his own bearing on the subject of rock decay in that country and the causes of the exceptional character and depth attributed to it by most writers. While appreciating fully the value and interest of the facts collected in the said paper, the present writer is somewhat inclined to question the hypothesis that furnished the motive for the collection, that is to say, the hypothesis that rock decay in Brazil is of an exceptional character requiring for its explanation the operation of special causes. The subject is one in regard to which he has felt great diffidence in formulating an opinion, even for his own private use, from his lack of familiarity with other regions of like petrographical and geological structure but situated under different climatic conditions, with which alone the comparison can properly be made. As it is probable, however, that in this respect he is in the same boat with many of the writers whose observations are relied upon for establishing the major premise in the case, he ventures to present some of his own observations on certain aspects of the subject.

Professor Pumpelly treating of the secular decay of rocks[2] has well remarked that "The depths of this decay, other things

[1] Bull. Geol. Soc. of Am., Vol. VII, p. 256.

[2] Bull. Geol. Soc. of Am., Vol. II, p. 210.

being equal, is determined by lapse of time, by the permeability and by the solubility of the constituents rather than by its hardness." If under permeability we include such features of geological structure as fissibility, jointing, etc., which facilitate the access of water to the interior of rock masses independent of the structure of the rocks *per se*, and the position of the planes of such geological structure with reference to the source of water supply, the law as above stated may be taken as covering the entire question to be considered.

Of the authors who have treated of rock decay in Brazil, the two whose opinions are entitled to the most weight, Agassiz and Hartt, believed (at least at the time of writing) in the general glaciation of the country by which the element of time in the formation of the present coating of decomposition products would be materially reduced. If, as Branner has recently shown to be probable,[1] these authors afterward modified their views regarding glaciation, they would doubtless have expressed themselves very differently on the subject of rock decay. At all events, for those who, like Branner and the writer, do not believe in the glaciation of Brazil, the time element is practically unlimited and the question becomes one as to whether or not the other factors of permeability and solubility are sufficient to account for the phenomena observed.

That the decomposition of Brazilian rocks, particularly those of the crystalline and semicrystalline groups, is both widespread and profound is abundantly proven by the numerous examples cited in Branner's paper. It is even probable that the cases cited fall far short of the extremes that may be found when the country is more fully explored. Thus far, however, no authentic Brazilian example in gneiss equals that of the bed in the Hoosic Tunnel decayed to a depth of 230 feet below the outcrop (in a glaciated region be it noted) cited by Hunt,[2] or in granite that of the Cornish example rotten to the depth of 600 feet, cited by Geikie.[3] According to the latter authority, the kaolinization of

[1] Jour. of Geol., Vol. I, p. 753.

[2] Am. Jour. Sci., 3d ser., Vol. XXVI, p. 198.

[3] Text-Book of Geol., 2d ed., p. 322.

the Cornish granites frequently extends to a depth of 50 or 60 feet, which represents fairly well the generality of cases of decay of this type of rock in Brazil.

Although not clearly expressed, it is evident that most writers in treating of the region about Rio de Janeiro, to which most of the observations on rock decay in Brazil refer, have assumed that the massive types of granitoid gneiss and, to a subordinate extent, of true granite, which are about the only rocks seen in a sound condition, represent the generality of rock in the region, and that the great masses of decomposed rock seen belong necessarily to these resistant types. It seems also to have been assumed that the accidents of relief giving abrupt differences of level of hundreds, or even thousands, of feet are mainly due to extraordinary erosion preceded by decay to extraordinary depths. The clearest expression of this view is found in the long-shot explanation by Agassiz of the so-called organpipe peaks (see Fig. 4 of Branner's paper) as hard vertical strata of gneiss left standing by the gradual decay of softer intervening strata. Up to the present time the peaks in question have never been examined close at hand by a competent geologist and as both gneiss and granite occur prominently in the range it is doubtful which of these two types of rock forms the peaks, or what may occur in the intervals between them.

It is certain, however, that the apparent uniformity of the massive types of rocks is due to their great resistance to decay in virtue of which they form the greater part of the hills which generally present bare rocky bosses at the summit while the flanks are heavily wooded. In the flanks between these hills basic eruptives, principally diabases, frequently appear which, though equally massive, seem to be more susceptible to decay although their apparent limitation to the lower levels may in part be due to their emergence along lines of fracture and of consequent weakness and of susceptibility to decay. Much more frequent in the lower grounds and in the hills of deeply decomposed material are schistose gneisses which from their lack of homogeneity and their position with the planes of fissibility

standing nearly vertically are highly permeable and so subject to decay that they are rarely found in a sound condition and have generally been overlooked. In the absence of a detailed geological study it is impossible to estimate, even approximately, the relative areas occupied by the comparatively impermeable granitoid gneisses and granites and these highly permeable schistose gneisses, but presumably the areas formerly occupied by the latter were at least equal to those of the former.

As regards the origin of the present abrupt topographical features the importance of faulting in their formation has scarcely been hinted at, and yet, as an examination of the excellent figures accompanying the paper cited will show, it seems to afford the most natural explanation of many of these features. Admitting that faulting on an extensive scale has taken place in the region, it will be readily seen that the downthrow side of a fault will be in very different conditions as regards the agencies of decomposition (even when the same type of rock is concerned) from the upthrow side. The latter receives only the water that actually falls upon it from the clouds and the time for infiltration (until a covering of decomposed material is formed that serves to retain a portion of the water) is practically limited by the duration of the rain. Under these circumstances the granitoid gneisses and granites of Rio de Janeiro and of the Serra do Mar region generally, are so nearly impermeable that the tops of the bosses are almost always bare and waste mainly by the process of exfoliation. On the slopes where the rock may be more shattered and where talus accumulates the meteoric waters have a greater scope for action particularly after vegetation has established itself on the decomposition crust that is gradually formed which, serving as a saturated sponge, greatly prolongs the time of infiltration of the surface waters to the underlying rocks. The downthrust side of a fault in addition to its own proper share of meteoric waters receives also a large part of the drainage of the upthrust portion not only during the downpour of rain but for some time after and the access of the water to the interior of the rock mass will be

facilitated by the fault plane and by any secondary shattering that may attend it. It may thus happen that in the distance of a few feet the same rock may be found almost perfectly sound and profoundly decomposed, and in cases of apparently abnormal decomposition the local conditions should be carefully studied before special causes (which will often be found to have respected adjacent rock masses) are called into play.[1]

Of the greater part of the examples that have been cited as showing the extraordinary extent of rock decay in Brazil no details regarding petrographic character and topographical position have, or can be, given from which an opinion can be formed as to whether or not the decay is normal or abnormal in character. The two exceptions are the cases of the Pedregulho reservoir in Rio de Janeiro and of the new shafts of the Morro Velho mine in Minas Geraes for both of which the figures are definite and the conditions are such that the decay observed may be considered as about normal for the kinds of rocks concerned.

[1] The subject of faulting has received very little attention in the study of Brazilian geology, but it is becoming apparent that many of the topographical features are due to faults and their determinative effects upon erosion rather than to erosion pure and simple as generally assumed. The evidences of faulting are most apparent in the regions of horizontal sedimentaries and bedded eruptives of the southern part of the country, but there are reasons for believing that they will also be found, perhaps on an equal scale, when detailed studies are made of the more ancient regions of eastern and central Brazil and of the more modern ones of the northern part of the country. For the latter region the possibility of faulting was suggested, rather too obscurely, as it appears, in a brief résumé of what was known of the Cretaceous in Brazil prepared by the present writer to accompany the monograph of Dr. C. A. White on the fossils of that age (Archivos do Museu Nacional do Rio de Janeiro, Vol. VII). The paragraph in which attention was called to the comparatively low level of the fossiliferous coastal basins as compared with the beds of the interior referred to the same age but with, so far as known, a different fauna, suggestive of a possible rise of the land occurring between the two faunas, has been strangely misapprehended by Dr. Branner who characterizes it as a hypsometric classification of formations. (The Cretaceous and Tertiary Geology of the Sergipe-Alagôas basin of Brazil, Trans. Am. Phil. Soc., Vol. XVI, 1889, p. 410.) As he unites the two faunas on no better ground than the attempted refutal of the supposed low level of the coastal basins, the epithet may perhaps with greater justice be applied to his own reasoning. The refutal in question is contained in the statement that the Cretaceous beds extend to within 150 meters of the top of the Serra de Itabaiana which, according to Mouchez,

The Pedregulho hill is an isolated elevation surrounded by tidal swamps and old beach deposits, of the type so well described by the Brazilians as a half orange. It thus presents the most favorable disposition for the preservation of the decomposed material except for the inevitable waste from rain washing and wind action, and (at least since the present topographical conditions were established) it has received no material from adjacent higher lands and only its own proper amount of atmospheric waters. The cutting away of the top of the hill for the reservoir foundation exposed the upturned edges of a highly schistose gneiss in which the different layers, rarely more than a few centimeters thick, vary greatly in the relative proportions of quartz, feldspar and mica (biotite) and consequently in permeability and susceptibility to decay. On the whole, however, it may be said that the rock represents the most susceptible type of the neighborhood and is in the most favorable conditions for rapid decay. At the depth of sixty-five feet from the original summit of the hill the rock was considered sufficiently firm to build upon though it was nowhere perfectly sound and many of the layers were completely earthy, partial decomposition evidently extended much deeper, and it may even be presumed that in some of the layers it may have extended nearly or quite to drainage level, that is to say to near the base of the hill 225 feet below the original summit.

In the case of the Morro Velho mine the rock concerned is a hard bluish clay slate, but without well defined slaty cleavage, standing nearly vertically. It is very uniform in character and

rises to an elevation of 700 to 800 meters above tide. Mouchez's figures are presumably a sailor's estimate at long range and are not in accord with two aneroid determinations which gave 520 and 608 meters. The section and detailed description of the mountain given in the same paper represent, in perfect accord with my own observations in the region, the Cretaceous beds as terminating at some distance from the base of the mountain, at an elevation of about one-third of its height and only slightly greater than that of the Tertiary which is stated to be about 200 feet. So far as the present evidence goes, therefore, the original estimate of about 100 meters as the maximum elevation of the coastal beds may still stand. As at no great distance the base of a very extensive and apparently very different horizontal series of secondary beds is at an elevation of about 300 meters, faulting is strongly suggested.

texture throughout a considerable thickness and, so far as can be judged from a simple inspection, should be one of the least susceptible to decay of the series of metamorphic schists to which it belongs. The notes given by Branner refer to two sets of shafts which should be carefully discriminated. The first were sunk at the bottom of a gorge, possibly a fault line, and thus were almost wholly below drainage level. The term "jointy" applied in the mine report to the first dozen fathoms would hardly be used by miners for a decomposed condition of the rock so that the depth of timbering (126 feet) is probably a measure of the depth to which the rock was shattered, perhaps through faulting, rather than decay. The new shafts, to which the information given by the present superintendent refers, are so situated that the depth at which "blasting rock" was found affords a good measure of the normal decay of this class of rocks above drainage level. They are on the side of a campo-covered ridge with a slope of 20° to 30° to the nearest stream some 300 feet below the mouth of the shafts. Decomposition here, though profound (155 feet), is still far above drainage level and probably under the same circumstances the more permeable rocks of the same series (especially those in which rapid alternations of layers of different composition and texture occur) would be found decomposed to a much greater depth. Thus in the adjoining Faria mine the depth cited (164 feet) probably refers to the depth of working and not to that of decay which under the circumstances of the mine and of its rock may be very much greater. On the other hand the soft bed intercalated in hard rock reported at Morro Velho at a depth of 755 feet could hardly have been a case of normal decay. So also the soft (friable) rock reported in the Cocaes (300 feet) and Gongo Socco (375 feet) mines probably do not represent decomposition as it is very doubtful if the rock of these mines (itabirite) was ever in a compact condition.

In traveling through the mining districts of Minas Geraes, which are mainly in campo, one gets the impression that rock decomposition is even more profound than in the forested coastal

region. In part the predominant rocks are of a totally different character representing in general terms the so-called crystalline schists with the exclusion of the true gneisses, and taken as a whole, it may perhaps be assumed that they are more susceptible to decay than the rocks of the coastal region in which gneiss and granite predominate. The comparison to be a fair one should be made between campo and forest region constituted by rocks of, as nearly as may be, the same character. The only elements for such a comparison are the superficial observations from the car window in traveling over the Central Railroad. In the long stretch of line in the forested region from Rio de Janeiro over the Serra do Mar and along the Parahyba and Parahybuna valleys to the crest of the Mantiqueira range one seldom fails to see sound rock, gneiss or granite or both, in the bottom (and often in the entire side) of cuttings that exceed a moderate depth. After passing the crest of the Mantiqueira and entering the campo region of Barbarcena sound rock is the exception rather than the rule in the cuttings though these continue as numerous and deep as in the other section and are also, for the most part, in gneiss and granite. The appearance, possibly deceptive, is that decomposition is even more profound in the campo than in the forest region. One plausible explanation for this difference is topographical, since in the forest region the road mainly follows the valleys and is consequently near drainage level whereas in the campo region it is more independent of the streams and is in general considerably above that level The rocks also, although of the gneiss and granite type, are apparently more acid in composition with a greater abundance of free quartz and of potash mica while magnesia, mica and amphibole are the predominant bisilicates in the rocks of the forest region. There are many indications that this difference in composition is accompanied by a greater susceptibility to decay although exact observations on this point have not been recorded. The differences noted in topographical structure and in rock composition may account for the apparently greater decay in the campo region and in that case the decay in the two regions

contrasted may be taken as approximately equal. So far as the present evidence goes, however, it is to the effect that in the districts of highly inclined crystalline and metamorphic schists of the states of Minas Geraes and Rio de Janeiro profound rock decomposition is not a concomitant of the present distribution of forests.

An interesting feature in the decay of some types of granite is that a considerable portion of the feldspar resists decomposition almost as well as the quartz and the rock disintegrates into a coarse gravel with comparatively little earthy, or completely decomposed, elements. This was first noticed on any considerable scale in a relatively arid region along the São Francisco River and was thought to be a case of arrested decay due to deficient rainfall. It has since been found, however, to be independent of climate as in the same region some rocks may be found decayed in this way while others in the immediate neighborhood are completely decomposed. Curiously enough the soils in which only a portion of the silicate elements of the original rock have become earthy are considered very good and in São Paulo these "rock-salt" (*salmarão*) soils are favorite ones with coffee planters.

With the rocks thus far considered, that is to say, the crystalline and metamorphic schists and their associated granites, decomposition, although very variable, is undoubtedly extensive and, very probably, is in many points much more profound than in any of those at which accurate measurements, or estimates, have been made. In general, however, it is to be measured by scores and not by hundreds of feet and, so far as the present evidence goes, the differences to be noted from one point to another are rather to be attributed to original differences in susceptibility, in permeability (due to original or superinduced textural and structural features), in the position of the rock masses in their exposition to the agencies of decay or with reference to the drainage level, rather than to climatic or biologic causes. With reference to this last point it would be interesting to compare the regions above considered with such a one as that mentioned by Allen[1] in the semi-arid region of Central Bahia,

[1] HARTT, Geol. and Phys. Geog. of Brazil, p. 314.

where gneiss and granite appear in a vast and almost level plain with only a slight covering of decomposed material. For this, however, data is lacking and it is impossible to say how much of the characteristics of this region is to be attributed to climate alone.

Turning our attention now to other groups of rocks, some of these are found to have resisted remarkably well the "torrents of hot water falling for ages in succession upon hot stones" in the phrase of Professor Agassiz. (The temperature of 140° to 150° F. recorded by Caldcleugh for rain water running over exposed rock surfaces would seem to require confirmation.) In crystalline rocks in which the inalterable quartz is replaced by silicates susceptible of alteration, such as nepheline and sodalite, much more rapid and profound decomposition might be expected than in the granites and gneisses. On the contrary, however, these, though decayed in places, are generally found in a sound condition at or near the surface. With many of these rocks a peculiar crust of kaolin and limonite forms on the surface of the decayed portion which serves as a very efficient protection for the inner portion of the masses. The more feldspathic types (augite-syenite) seem, contrary to what might be expected, to be more susceptible to decay than those rich in the silicates above named. The character of the bisilicate element also seems to be of considerable importance as in a recent excursion to the peak of Itatiaia no difficulty was experienced in obtaining satisfactory specimens from the exposed blocks, or bosses, of nepheline-syenite, augite-syenite, phonolite and even tufas, whereas a very extensive exposure of mica-syenite was searched in vain for a perfectly sound sample of the rock. In this, as in some other cases, it looks as if some of the elements set free by the decay of the rock itself might be more potent for continued decomposition than those derived from the atmosphere. The general soundness, though many exceptions occur, of the porphyritic (phonolitic) types of these rocks is especially noticeable as it is understood that in many temperate regions this type, though presumed to be geologically newer than in Brazil, is considered to be particularly susceptible to alteration.

An opportunity for observing the phenomena of decomposition under substantially the same climatic and biologic conditions but with reference to a totally different series of rocks is afforded by the recent notable extension of coffee culture in the interior of the state of São Paulo with the accompanying extension of the railway system. No critical study of this region has as yet been made and, as in nearly all that precedes, the observations (whether those of the writer or of others) must be taken as railroad geology and, as such, subject to future revision.

The region in question lies immediately to the west of that above considered and in so nearly the same conditions as regards latitude, elevation, rainfall, and forest distribution that the differences may be considered as unimportant for the present discussion. The features of geological and topographical structure and of the character of the rocks are however widely different. The dominant geological and topographical features are given by soft shales and sandstones of late palæozoic (Permian?) and early secondary (Triassic?) age which are practically horizontal though much disturbed by faults and dykes and sills of basic eruptives. The latter belong exclusively to the group of augite-porphyrites as defined by Rosenbusch and represent all the varied phases of that group. According to all the indications at present known the region has stood as dry land ever since early secondary times. Much of it is in campo but considerable forest tracts occur. No direct relation can be traced between the distribution of forest and campo and the character of the underlying rocks, though in general it may be said that campo predominates over forest in the areas in which the sedimentaries give character to the surface soil, the contrary being the case where the eruptives come to the surface.

In this region the evidences of profound decomposition are far less prominent than in the mountainous districts above referred to. The railroad cuttings are not deep, seldom exceeding a half dozen meters, but they rarely fail to show some rock in a comparatively sound condition which frequently extends to within a meter or less of the surface. The sedimentary rocks

are almost invariably quite soft even where they show no signs of decay, and go to pieces by a kind of slacking process when broken up and exposed to the air, though they may have required blasting in the original opening of the cuttings. The eruptive rocks vary greatly in their resistance to decay. The porphyritic types, especially when they are amygdaloidal, are often in a state of incipient, or complete, decomposition to a depth quite as great, or perhaps even greater, than that noted in the granite and gneiss regions, while the types approaching diabase in character are often sound, or only broken up into bowlders of decomposition, quite to the surface. As the decay of these basic rocks affords the favorite coffee soil, the famous *terra roxa*, the forested tracks where they occur have been very generally cleared and planted, and the coffee orchards (where the underlying rock is diabasic) seldom fail to show loose stones and frequently continuous outcrops of rock at the surface. Many of these orchards are on almost level tracts, so that the comparative thinness of the capping of decomposed rock cannot be attributed to excessive washing. In short, considering the length of time that this region has stood as dry land and the favorable topographical disposition for the preservation of the products of decay, the average amount of rock decomposition may be said to be surprisingly small rather than surprisingly great, and where it is profound, the cause must be sought in the susceptibility of the rocks themselves and not in climatic or biologic conditions.[1]

ORVILLE A. DERBY.

[1] In treating of the organic agencies affecting the soil, Dr. Branner notes that the action of earth worms is much less important in Brazil than in temperate regions. The same remark has been made by Mr. H. H. Smith, a very acute and accurate geological and biological observer. My own experience is so far in accord with these observations that only once has decided evidence of the action of earth worms been noticed. This case however was so striking that the absence of other observations may perhaps be attributed rather to lack of attention to the subject, or of favorable conditions for observing the action of these humble manipulators of the soil, and not to their absence. An old pasture that had been wet by a shower after a burning that had completely bared the surface, was so thickly covered with the vermicular heaps thrown up by earth worms that over a space of several acres it was almost impossible to put down the hand without touching one or more of them.

ITALIAN PETROLOGICAL SKETCHES.

I. THE BOLSENA REGION.

Introduction.—The number and easy accessibility of its volcanoes render Italy an enticing field for the geologist. The peculiar characters of their eruptive rocks, which are rich in potash, and in which leucite is a most common mineral, render them of special interest to the petrologist. It would seem, however, judging from a quite extensive survey of the literature, that the country has been rather neglected in recent years by petrologists ; since, except for a comparatively small number of modern papers describing limited districts, we must turn for many of our descriptions to the writers of more than a quarter of a century ago. Few attempts also have been made to correlate the facts in our possession for the purpose of determining the general petrological characters of the Italian province.

In the autumn of 1894 the writer had the opportunity to pay brief visits to most of the Italian mainland volcanoes and make collections of their representative rocks. A study of the specimens collected revealed so many new and interesting features that it was decided to publish a series of short papers on various Italian volcanoes. In these the separate rocks will be described, and some general conclusions which have been drawn from their study will be presented in a final paper. The work of the modern school of Italian petrographers will be used and quoted extensively, since it is comparatively little known to the outside world. As the time devoted to each volcano was all too brief these papers must be sketches merely, and will be predominantly petrological in character.

I. THE BOLSENA REGION.

Bibliography.—The work of the early geologists—such as Breislak, Brocchi, Pareto and Pilla—need not detain us, as they

are of little interest in the present connection. We may note, however, that Pareto in 1844 pointed out three centers of activity, Latera, Torre Alfina and Montefiascone, around lake Bolsena.

Vom Rath[1] in 1868 gave a detailed description of the region. His paper is largely topographical, with some descriptions of the tuff and lava beds and a couple of analyses. He does not consider the lake as the remains of one large crater, but thinks that it is due to a sinking of the surface (*Einsenkung*), and that the circle of hills was produced by eruptions at different points around this tract.

Stoppani[2] in 1873 gives a description of the volcano, in the course of which he expresses his belief that the lake is in reality the site of a vast crater, slightly enlarged by erosion; at the same time recognizing the existence of parasitic cones, of which he gives Monte Rado near Bagnorea as an example.

In 1888 Verri[3] published a geological sketch of the region, the rocks collected by him being handed over to Ricciardi for chemical analysis and to Klein for petrographical description. After a brief historical and topographical description he discusses the order and epoch of the eruptions, and then describes in detail the various eruptive centers around the lake. The origin of this he holds to be that given by vom Rath. He considers that the tuffs of the region were erupted in the condition of mud — a conclusion, it may be added, which is strongly combated by other Italian geologists.

Klein's[4] article is composed of petrographical descriptions of Verri's specimens, which include most of the prominent rocks of the region. Though the descriptions are short and concise, they give a very good idea of the rocks; and I am happy to say that my own studies of specimens from the same localities substantiate Klein's descriptions in almost all points. The paper

[1] VOM RATH, Zeit. d. d. geol. Gesell., XX, 265–294, 1868.

[2] STOPPANI, Corso di Geologia, Milano, 1873, III, 376, 386.

[3] VERRI, Boll. Soc. Geol. Ital., VII, 49–99, 1888.

[4] KLEIN, Neu. Jahrb., B. Bd., VI, 1–35, 1889.

also contains the complete set of Ricciardi's analyses, which were published by him elsewhere.[1]

In the same year Moderni[2] published a short paper on the trachyte and tuff of Rispampani near Toscanella, which lies to the south of Lake Bolsena. He states that the trachyte forms a dome resting on Eocene beds. The trachytic tuff is remarkable for its radiating columnar structure, and resembles a lava in external characters.

In an important paper on the extinct volcanoes of the northern Apennines de Stefani[3] takes Lake Bolsena as the type of the crater-lake eruptions and gives a detailed description on the basis of his own observations. He differs from Verri in several points, notably in regard to the genesis of the lake, which he regards as a large central crater, at the same time recognizing the existence of flank eruptions, and comparing the volcano to those of the Hawaiian Islands. The interesting general conclusions regarding the Italian volcanoes which he gives at the end of his paper will be noticed elsewhere.

The last writer to treat of the region is Bucca[4] who gives short petrographical descriptions of a number of the leucite rocks.

Topography.—The center of the region is Lake Bolsena, which lies northwest of Rome and southwest of Orvieto, in Lat. 42° 35′ and Long. 12° 20′ E. Its shape is quite regularly elliptical, the major axis running north and south. Its dimensions are 13 by 10 kilometers, with a surface area of about 112 square kilometers, being thus the largest crater-lake in Italy, and one of the largest in the world. The surface of the lake is 305 meters above sea level, and the greatest observed depth is 140 meters. The two small islands of Bisentina and Martana rise a few meters above the surface in the southern and southwestern parts of the lake. They are composed chiefly of tuff and seem to be the remains of small volcanic cones.

[1] RICCIARDI, Gazz. Chim. Ital., Palermo, 1888.

[2] MODERNI, Boll. Com. Geol. Ital., X, 19–25, 1889.

[3] DE STEFANI, Boll. Soc. Geol. Ital., X, 499–537, 1891.

[4] BUCCA, Rivista Min. e Crist., 18–30, 1893.

Surrounding the lake and sloping steeply down to its waters (leaving only a narrow shore margin), is a girdle of hills whose most elevated points on the north are 600 to 680 meters above sea level, and hence 300 to 375 above the surface of the lake. Towards the south they diminish in height, a feature which this crater possesses in common with others of Italy.

These hills are made up of volcanic material, chiefly leucitic lavas and tuffs, though to the north of the lake considerable "trachyte" is found. In places fine sections of superposed tuffs and lava streams are exposed, and in the latter a columnar structure is sometimes very well developed. From the crest encircling the lake the surface slopes gradually down on all sides, till the volcanic ejectamenta thin out in tuffs resting on the Sub-Apennine pliocene marine marls.

The whole district occupied by volcanic material thus forms a low lenticular mass (with the lake in a hollow at the center), whose outer sides slope at angles of 12° to 15°. Its diameter is about 40^{km} and its total area some 1300 square kilometers, as has been estimated by Stoppani and Verri. Erosion of the soft tuffs has cut up the surface to a great extent, producing characteristic radiating ravines, which de Stefani compares with our western canyons in miniature, and forming isolated buttes such as those on which the towns of Orvieto and Civita di Bagnorea are so picturesquely situated.

Lying immediately to the west of Lake Bolsena is another depression, or rather plain surrounded by a girdle of hills, also of least height to the south, its circle impinging on that of the Bolsena Crater. This crater, which is known as the Latéra Crater, is smaller than that of Lake Bolsena, having a diameter of about 7^{km}. The small Lake Mezzano, which occupies part of the area, preserves well the form of a crater, and may be looked upon as the site of the last eruption of the Latéra volcano. This seems, from the descriptions, to be a distinct eruptive center, though nothing is said by any of the writers mentioning it as to its age relative to that of the Bolsena volcano. It would seem, however, to be the more recent, since the original crateriform

character of both the exterior Latéra and interior Mezzano craters are better preserved than in the case of Bolsena; and also because it is, according to Stoppani, at present in a solfataric state.[1] The lavas of Latéra are entirely leucitic, so far as is known, no trachytes having yet been found at this center.

To the north of the Bolsena Region lie a number of small isolated volcano vents, such as the "trachytic" Monte Amiata and the basaltic hill of Radicofani. To the east are the Tertiary deposits flanking the main line of the Apennines, and to the south lies the closely similar volcanic Viterbo Region, which will form the subject of the next paper.

As to the character of the eruptions little need be said here, though I may insert de Stefani's summing up of the subject. He says:[2] "In conclusion we can hold that the volcano, submarine in the beginning, became later subaërial and erupted in the midst of a low and swampy region like the Maremme (marshes) of the present day in the same country." He thinks that the latest eruptions of tuff were dry and probably fell on dry land.

Discussion of the origin of the lake must be deferred to another place, since the existence of such crater-lakes is a feature common to several of the regions to be described. We may note, however, that there are two prominent theories. One is that of vom Rath and Verri, who regard the lake as a sunken tract, the sinking being due to the ejection of material from various points which forms the hills surrounding it. The other is that held by Stoppani and de Stefani, who consider the lake as the volcanic center, the remains of a large crater which has been enlarged by explosions and the falling in of its walls; and from which was ejected the greater part of the volcanic material, small flank eruptions also adding to the mass of the volcano. I may remark, in anticipation, that the weight of evidence and analogy is in favor of the latter theory.

[1] As I did not visit this western part of the region I cannot say whether one crater circle cuts the other or not, and I can find no mention of this point in the literature.

[2] De Stefani, op. cit., 526. He notes that von Buch expressed the same view about 1810.

As to the period of the eruptions de Stefani points out that in certain places, especially in the northern part, volcanic products alternate with marine fossil-bearing strata of the late Pliocene; and we may assume that the main eruptions began in the Pliocene period. Both he and Stoppani also give reasons for thinking that the latest eruptions were contemporary with man and geologically very recent.[1]

PETROGRAPHY.

The petrography of many of the Italian volcanoes is involved in considerable confusion. This is especially true of the regions immediately around the great crater-lakes. We shall see that these large volcanoes erupted a great variety of lavas, while the smaller eruptive masses flanking this main line offer much less variety, each separate mass being largely composed of one definite type of rock. The Bolsena volcano is no exception to this rule, which de Stefani[2] has brought out very clearly.

The confusion results partly from the tendency which many of the types have, especially among the leucitic rocks, of grading into one another; and partly from the presence of peculiar non-leucitic rocks which do not fit exactly into any place in our scheme of classification, and whose naming is largely a subjective matter.

It has lately been pointed out by Brögger[3] and Pirsson[4] that at the present stage of the science we must recognize the quantitative chemical and mineralogical relations as well as the qualitative. Brögger[5] has also made an able plea for the recognition of transition groups, the importance of which in our classification he brings out very clearly. With Brögger's views on the subject I, like Pirsson, heartily concur; and his principles will be recognized in the classification of the rocks which we shall

[1] STOPPANI (p. 384) quotes Gualterio as arguing for the probability of the formation of the Bolsena volcano during the paleolithic period.

[2] DE STEFANI, op. cit., 550.

[3] W. C. BRÖGGER, Gest. d. Grorudit-Tinguait Serie, Kristiania, 92, 1894.

[4] L. V. PIRSSON, Am. J. Sci., L, 478, 1895.

[5] BRÖGGER, op. cit., 93, and Eruptionsfolge bei Predazzo, Krist., 1895.

examine. This will involve the proposal of some new names, but the baptismal rite will be indulged in as sparingly as may be.

For the present we must confine ourselves to the Bolsena volcano, and may say that two prominent types exist, the trachy-andesitic and the leucitic rocks. Even these two prominent types grade into one another to a slight extent, though they can as a rule be readily distinguished. In the following pages I shall describe my own specimens, turning to Klein and Bucca for descriptions of rocks which I was unable to collect. The tuffs and the metamorphosed ejected blocks will not be touched upon. Ricciardi's analyses cover the ground so completely that only one fresh analysis was made, of the important Bolsena "trachyte." Vom Rath's analyses and the best of Ricciardi's will be inserted later.

Vulsinite.—Vom Rath first called attention to the abnormal chemical character of the "trachyte" of Bolsena, though he speaks of it as containing no plagioclase, probably owing to the rarity of the multiple twinning. As will be seen from Klein's descriptions and my own, and from the analyses, the peculiar "trachytes" of the region are remarkable; mineralogically for their richness in plagioclase and the frequent occurrence of olivine as an essential constituent, and chemically for their low silica and high lime and magnesia. Therefore they are not trachytes proper, but correspond to the trachy-dolerites of Abich[1] and Hartung,[2] and to some of the andesitic-trachytes of Rosenbusch,[3] and we shall see that they may be regarded as effusive representatives of Brögger's abyssal monzonites. These olivine-free effusive rocks will be called by the name of *Vulsinite*,[4] from the Etruscan tribe, Vulsinii, formerly inhabiting this region. Those carrying olivine belong to a peculiar type which will be described in the next paper.

[1] ABICH, Nat. n. Zusammensetz. d. Vulk. Bild., p. 101, 1841.

[2] HARTUNG, Azoren, Leipsig, p. 92, 1860. Cf. MUGGE, Neu. Jahrb., Vol. II, p. 201, 1883.

[3] ROSENBUSCH, Mikr. Phys. Vol. II, p. 600, 1887.

[4] The name Bolsenite has already been used by H. O. Lang (Min. Pet. Mit., XIII, 143, 1892) for one of his purely chemical groups, which embraces certain leucitic rocks.

These rocks are not very abundant in the region, and seem to be more common in the northern part than elsewhere. In certain cases they belong to the earlier eruptions, prior to those of the leucitic rocks. Purely alkali feldspar-trachytes seem to be unknown about this center, unless Moderni's trachyte of Rispampani belongs here, a point which his brief description does not permit us to decide. The plagioclase end of the series is represented by the augite-andesite of Monte Rado, which is also olivine-bearing.

The only specimens of vulsinite in my possession were collected from a small eminence on the eastern shore of the lake, immediately to the north of the small town of Bolsena. The locality is mentioned by Verri and de Stefani, and the rock is the same as that described by Klein (p. 8), with whose descriptions my specimens agree very closely. It is probably identical also with the trachyte of vom Rath (p. 291), though Nassini's quarry, whence he obtained his specimen, does not seem to be known at present. The rock belongs, as we shall see, to one of the earliest outflows.

Megascopically it is fine-grained and compact, with marked eutaxitic structure. The greater part is light ash gray, but mottled with spots and streaks of dark gray and yellowish brown. The structure here seems to be due to a mingling of magmas of somewhat different composition. Many glassy phenocrysts of feldspar, as well as smaller ones of augite and a few of biotite, are to be seen. The specific gravity is 2.534 at 25° C.

The feldspar phenocrysts are both alkali feldspar and plagioclase, the former in the majority but the latter quite common. Twinning, according to the Carlsbad law is not rare in the orthoclase, and one very perfect example of a Baveno twin was seen. While twinning is the rule with the plagioclase, yet multiple lamellæ are not often seen, and some untwinned crystals occur. Zonal structure is not frequent. The polarization color furnishes the readiest method of distinguishing between the two feldspars, that of the plagioclase in my sections, which are about $0^{mm}.2$ thick, reaching the light straw yellow of the first order. The

difference in refractive index is also marked. Inclusions are not very abundant and are usually small spots of glass, with some augite, magnetite and apatite crystals. In the alkali feldspar phenocrysts inclusions of plagioclase of some size are occasionally seen, but the reverse was not noticed.

The examination of plagioclase phenocrysts in the slides was made with care and resulted in establishing the fact that they are anorthite. In a section cut approximately parallel to *c* (001) an optic axis emerges almost perpendicularly, and the angle of its extinction is 38° with the trace of the plane *b* (010). The alkali feldspar border (to be described presently), in this case extinguishes parallel to the same plane of the anorthite crystal. In another section cut parallel to *b* (010) the plane of the optic axes (determined by the emergence of an axis at the border of the field), formed an angle of —34° with the basal cleavage cracks, while the individuals of the Carlsbad twin extinguished at 29° and 30½° on each side of the twinning plane. The border around this crystal extinguished at an angle of 11° with the basal plane of the anorthite. This determination of the plagioclase as anorthite confirms Klein's observation of its basicity.

Apart from the composition of the plagioclase, the most interesting feature of the feldspars is brought out between crossed nicols. It is then seen that both alkali feldspar and anorthite phenocrysts are surrounded, almost without exception, by a border or mantle of alkali feldspar of late growth. This forms one individual around the phenocryst proper, as shown by the simultaneous extinction of the whole border. The outer edge is in general very irregular, ending with an uneven and often uncertain line against the groundmass; though here and there there has been an attempt to fill out the crystal form, resulting in quite sharply defined straight edges.

The mutual extinctions prove that the mantle is orientated like the nuclear crystal, and if the inner orthoclase crystal be twinned the twinning is continued uninterruptedly in the outer mantle. This is also true to some extent of the Carlsbad twin-

ning of the anorthite crystals, and to a less extent of their multiple lamellæ due to albite twinning. Examination by Becke's method shows that there is no difference in refractive index between the substance of the mantle and the orthoclase phenocrysts, so that the two are to be distinguished (especially in ordinary light) by the differences of limpidity, while the higher index of the anorthite is strongly marked. The extinction angle of 11° in sections parallel to *b* (010) already mentioned indicates that the mantles are of soda orthoclase.

The border shows a well-developed micropoikilitic structure, since it contains like the groundmass many small augite and magnetite grains. In consequence of this there is scarcely any difference to be observed in ordinary light between the mantle and the surrounding groundmass, which seems to come quite up to the edges of the feldspar phenocryst.

Klein observed this feature in several rocks of the region, and Bucca likewise mentions a similar mantle in describing the leucite-phonolite of Bagnorea.

This mantle must be carefully distinguished from the phenocrystic crystal, as it is evidently the product of a distinct and later period of growth, and is almost identical with the holocrystalline groundmass. The only difference between the two is that under the influence of the pre-existing feldspar phenocryst the orthoclase substance crystallized as a single individual, the orientation of this later growth being determined by the nuclear crystal, and small crystals of augite and magnetite being included in a normal way. In the other part of the groundmass, away from the orientating influence of the large feldspar phenocryst, the orthoclase substance crystallized at many points as separate small individuals with diverse orientations, forming a normal trachytic groundmass.

The frequency with which plagioclase is surrounded by orthoclase in parallel position is well known and is noted by Rosenbusch,[1] though the present case differs somewhat from those mentioned by him. We do not have here the production

[1] ROSENBUSCH, Mikr. Phys., I, 638.

of definite crystal forms, but rather the orientation of the groundmass into micropoikilitic patches, though the principle involved is the same in both. Similar mantles of alkali feldspar about labradorite have been observed by Iddings[1] in rocks of the Yellowstone Park, by Pirsson[2] in the syenite of Yogo Peak, Montana, by Merrill[3] in rocks from Montana, and by Kolenko[4] in trachyte from New Zealand.

The borders in question are closely analogous to the micropoikilitic patches of quartz described by Miss Bascom,[5] Iddings[6] and Clements,[7] especially the last. Miss Bascom shows reasons for thinking the structure in the South Mountain rocks to be of secondary origin, while at the Electric Peak they are primary, as they also probably are in the Michigamme District according to Clements.

In the case before us the evidence is entirely in favor of their primary origin. As will be seen the phenomenon was observed in many other rocks of the Italian volcanic regions. These rocks are all comparatively recent lava streams, fresh and unaltered, so that there can be no appeal to metamorphic processes. The whole appearance of the border, with its included grains and its identity with the groundmass (except in its individual orientation), leaves no doubt that the effect is due simply to the orientating influence of the feldspar phenocrysts during solidification of the groundmass magma.[8]

The remaining phenocrysts are of augite and biotite, but offer few features worthy of note. In the normal gray vulsinite the augites—both phenocrysts and groundmass crystals—are of a pale olive green, while in the eutaxitic brown streaks they are of a bright golden-yellow color. The biotite phenocrysts are pale

[1] IDDINGS, JOURNAL OF GEOLOGY, III, 940, 941, 1895.

[2] PIRSSON, Am. J. Sci., L, 471, 1895.

[3] MERRILL, Proc. U. S. Nat. Mus., XVII, 645, 1894.

[4] KOLENKO, Neu. Jahrb., 1885, I, 9.

[5] F. BASCOM, this Journal, I, 816, 1893.

[6] J. P. IDDINGS, Electric Peak, 12th Rep. U. S. G. S., 589, 1892.

[7] J. M. CLEMENTS, this Journal, III, 814, 1895.

[8] Both Klein and Bucca consider them primary but late growths of orthoclase.

brown, irregular in outline and show without exception great "magmatic" alteration. The product is largely magnetite with little augite, and penetrates deeply and irregularly into the crystal. Magnetite is quite abundant, both in the groundmass and as phenocrystic grains. The groundmass is typically trachytic, and consists essentially of a holocrystalline cement of soda orthoclase flakes and laths, which latter are more abundant in the gray vulsinite than in the brown streaks. There is little evidence of flow structure. With these are numerous grains of yellow or greenish augite, magnetite grains and some apatite needles and grains of titanite. There are also seen some small crystals of a peculiar brown hornblende, which will be described at length later. No glass is present and the rock does not gelatinize with acids.

Here and there one sees coarse-grained, holocrystalline clusters of large augite, plagioclase, orthoclase and magnetite grains, which are probably segregations, as Klein suggests. The augite is generally bright golden-yellow, but a few pale green diopside grains are to be noticed. It is xenomorphic towards the feldspars, filling the interstices between them. The feldspars contain large dusty apatite crystals.

Three analyses of this rock are inserted here.

	1	2	3
SiO_2	59.22	57.97	58.21
TiO_2			Tr
Al_2O_3	18.56	17.65	19.90
Fe_2O_3		0.63	4.07
FeO	6.06	7.50	0.87
MnO		0.09	
MgO	1.12	1.71	0.98
CaO	2.96	5.53	3.58
Na_2O	4.87	1.50	2.57
K_2O	6.66	5.31	9.17
P_2O_5		0.42	not det.
Ignit.	1.14	1.82	0.74
	100.59	100.13	100.09

1. Vulsinite, Nassini's Quarry, Bolsena, vom Rath, op. cit., 291.
2. " Bolsena, Ricciardi anal. Klein, op. cit., 8.
3. " Bolsena (665), Washington anal.

From the above description and analyses we may then define the *vulsinites* as effusive rocks *occupying an intermediate position between the trachytes and the andesites.* They are characterized mineralogically by the presence of alkali feldspar with a large amount of basic plagioclase (labradorite to anorthite) together with augite and diopside. Hornblende and biotite are not abundant in the type specimens, though they may be present in large amounts in other varieties, as will be seen later. Olivine is wanting, or if present is so in only accessory amounts. Chemically they are rocks of medium acidity, SiO_2, from about 55 to about 60 per cent., though it may run slightly above or below these figures. Alumina and iron are present in medium amounts, magnesia is low, lime rather high (3 to 6 per cent.), and alkalies (especially potash) high. Of the analyses above No. 3 may be regarded as typical. From an examination of this it is seen that after the formation of magnetite and pyroxene considerable lime is left over. Since part, if not most, of the alkali feldspar is a soda orthoclase and the amount of soda present is small this lime must go to form anorthite.

Klein describes very similar rocks which belong to the vulsinites. Those from Torre Alfina and San Lorenzo, north of Lake Bolsena, are very high in silica and lower in potash (according to Ricciardi's analyses) than we would expect (*cf.* anal. 5, p. 565). Their groundmass is brown, phenocrysts of glassy feldspar, biotite and augite are visible, and they seem not to be quite fresh. Among the phenocrysts sanidine largely predominates over the plagioclase, which is basic. Some olivine is present, but since the magnesia is low its quantity cannot be very great. The groundmass is very glassy, the base being brown through the presence of globulites. Orthoclase, plagioclase and magnetite are present in the groundmass, but augite is not mentioned. These rocks seem to resemble those of Monte Amiata described by Williams, and their relations will be discussed later.

The "trachyte" of San Magno, to the west of the lake, approaches nearer to the Bolsena rock, the silica being 60.03 but the potash is still rather low, though higher than the soda

(anal. 4, p. 565). It is quite free from olivine. Plagioclase is abundant and basic, giving extinction angles up to 30° on each side of the twinning plane. The groundmass is holocrystalline and composed largely of orthoclase and plagioclase, with augite, biotite and magnetite. In it occur round spots of very feebly doubly refracting substance which closely resemble leucite. Klein comes to the conclusion, however, that these are not leucites, since only 0.28 per cent. of K_2O is extracted from the rock by HCl, but that they are of glass in a condition of strain. From his description they seem to be the same — or very similar to — certain spots in the groundmass of a leucite phonolite from Lake Bracciano, which will be described in another paper. These are of "pseudo-leucite," a mixture of nepheline and orthoclase probably due to the alteration of leucite crystals.

The "olivine-bearing andesitic trachytes" of Sassara and Mont' Alfina (Klein, p. 6) belong rather to a type of rock which will be described in the next paper than to the vulsinites. The silica is lower (56.32 per cent.) and magnesia quite high (anal. 6, page 565). Basic plagioclase phenocrysts, with extinction angles up to 30° on each side of the twinning plane are very abundant, more so than orthoclase. Olivine, augite and biotite also occur as phenocrysts. The groundmass contains little glass, and is made up of the same minerals that compose the phenocrysts, except that olivine is wanting.

Andesite.—An augite-andesite is met with as the last product of eruption at Monte Rado, west of Bagnorea, and is described by Klein (p. 32). This, it will be remembered, is one of Verri's five centers of activity, and probably poured forth at an earlier stage the leucitic lava streams met with at Sassi Lanciati, Bagnorea and Porano. It is without doubt one of the last eruptions of the Bolsena volcano. Monte Rado is described as a hill covered with scoriæ, lapilli and bombs, and the specimen examined by Klein comes from the upper part. As I could not visit the locality I quote from Klein's description.

The phenocrysts are of plagioclase, which is apparently labradorite, and shows zonal structure, augite, brown biotite and

olivine. These lie in a very glassy groundmass containing fluidally arranged plagioclase laths and augite microlites. Neither nepheline nor leucite could be detected. It is possible that a small amount of sanidine may be present. Klein remarks that, though the appearance and the presence of olivine would suggest a basalt, yet that the analysis (No. 7, page 565) does not agree with this determination, and that consequently it must be called an olivine-bearing augite-andesite.

Leucite Rocks.— In our classification of these rocks we are confronted with two difficulties which render the bestowal of correct names, in so far as this is an important matter, an affair of some doubt. The first is the fact, already mentioned, that the various types grade into one another mineralogically to such an extent that the drawing of hard and fast lines is rendered in many cases impossible.

The second difficulty is the fact that two separate systems of nomenclature have been proposed by leading petrologists for some of the leucite rocks. The following are the names of Rosenbusch[1] and Zirkel.[2] An effusive rock composed essentially of leucite and orthoclase Rosenbusch calls a leucite-phonolite, while Zirkel calls it a leucite-trachyte. If nepheline is added to the above combination it becomes, according to the former a leucitophyr, according to the latter a leucite-phonolite. It is unfortunate that such a diversity should exist, especially in the double use of the name "leucite-phonolite." It is true that it is an embarrassment which seldom confronts one, since both groups are of very rare occurrence. In the present case however we are, so to speak, in their native land, and a decision must be come to in regard to the matter. Zirkel's objections to Rosenbusch's use of the term leucite-phonolite seem well grounded, since through long use one connotes the presence of nepheline with the name phonolite. Another objection which might be brought up is that the name leucite-trachyte for this group of rocks has the priority, since it was used by vom Rath[3] as far back as 1867.

[1] ROSENBUSCH, Mikr. Phys., II, 621, 1887.

[2] ZIRKEL, Lehrbuch, II, 427, 1894.

[3] VOM RATH, Zeit. d. d. Geol. Ges., XIX, 584, 1867. Cf. ROSENBUSCH, II, 621.

It is true that Rosenbusch uses the term phonolite in a very broad sense, covering the leucite as well as the nepheline rocks. The advisability of such an extension of its meaning may well be doubted. As to the term leucitophyr used by Rosenbusch, I must agree with Zirkel in his objections to it, as a name which does not convey any idea of the presence of nepheline, and conveying the erroneous idea that a porphyritic structure is characteristic of it. Further discussion of this subject is uncalled for, but the terms leucite-trachyte and leucite-phonolite will be used in Zirkel's sense.

Leucitite.—Of true leucitites there seem to be comparatively few in this region compared with others of Italy, such as those of Bracciano and Albano. Klein describes eight which belong to this group, though they all carry a little plagioclase, and Bucca also notices a few. They are basic, with SiO_2 from 48 to 50, and Ricciardi's analyses show less K_2O than we would expect to find. Megascopically they are basaltic looking, dark gray and very fine-grained and compact, with only rare phenocrysts of leucite and augite. Their micro-structure is the characteristic one, well known to most petrographers, of a groundmass made up of round spots of leucite with interstitial augite needles.

The most typical of my specimens is from a flow near the lake shore, about half a kilometer north of Bolsena. Its color is dark gray with a slightly greenish tinge.

Under the microscope it shows the typical structure. Leucite crystals are extremely abundant in the groundmass, few being of phenocrystic dimensions. With them are some large green augites, a few biotite crystals almost wholly "altered," and one or two well shaped orthoclase phenocrysts. These lie in a cement composed of colorless glass, with a felt of slightly greenish augite microlites, some magnetite grains and very few plagioclase laths.

The leucites, which show feeble double refraction, seldom reach a diameter greater than $0^{mm}.25$, and from this run down to microlitic dimensions. These smallest leucites show only

rounded outlines, but those of a larger size offer more variety. While some give sharp, normal, eight sided sections, with a few small, isolated inclusions, the greater number show more or less perfect skeletal forms. Their sections consist of simple four-armed crosses; eight-rayed stars with four alternate arms larger than the intervening ones, and thick at the ends or with a short process projecting from the end on each side; six-rayed stars with thick and equally developed arms at angles of 60°; finally, sections resembling equilateral, spherical triangles in outline, generally with triangular spots of glass at the apices.

The forms are evidently due to sections of skeleton crystals, and all may be referred to leucite skeletons like those described by Senigaglia[1] in a lava of 1753 from Vesuvius. They are developed not so much along axes as along planes from the center of the crystal to all the trapezohedral edges, the crystals being really trapezohedrons with deeply sunken faces and high salient edges.

Similar forms are to be found in other Italian leucitites, as from Lake Bracciano and the Alban Hills. Pirsson[2] has observed almost identical forms in rocks from the Bear Paw Mountains in Montana and gives an interesting discussion of their growth to which the reader is referred.

Another typical leucitite comes from Sassi Lanciati (Tossed Rocks), a locality about 2^{km} south of Bolsena on the lake shore where the road passes a lava stream about 10 meters high, showing well developed columnar structure. In the early days of geology this was apparently a well-known and oft-cited locality, but more accessible and better examples of this structure have thrown it into oblivion.[3]

The rock is described by Klein (p. 21), and is very similar to the first one described in this paper. It may be noted however that the inclusions in the leucite are rings of augite microlites arranged tangentially near the borders, and that no skeleton

[1] SENIGAGLIA, Neu. Jahrb., B. Bd. VII, 418, 1891.

[2] PIRSSON, Am. J. Sci., I, 1896.

[3] VOM RATH, op. cit., 292.

forms are present. Plagioclase is almost wholly lacking. Its specific gravity is 2.311 at 26° C.

With the leucitites may be classed the rock from a flow at the Osteria di Biagio, on the road from Orvieto to Bolsena. It is rather a nepheline leucitite, as it contains considerable nepheline in the groundmass. Its rather dark greenish gray groundmass is compact, but shows some narrow vesicular cavities, generally in planes parallel to each other as determined by the flow. In the groundmass are many small clear leucite phenocrysts and a few small black augites. Into the cavities project very many small stout hexagonal prisms of nepheline, which are coated with an opaque white substance, but are clear grayish white within.

Its appearance in thin section closely resembles that of the leucitites already described, the leucites being round, with feeble double refraction, and with included rings of augite microlites. The pyroxene of the interstitial groundmass is an ægirine-augite, and the base generally exhibits faint double refraction. Examination with acids shows that this is largely nepheline, though a small amount of glass seems to be present. No crystal sections of nepheline were to be found, and in the body of the rock it acts as cement and is undoubtedly the last product of crystallization. In the groundmass a few small colorless laths were to be seen which may be referred to orthoclase, indicating a transition toward the leucite-phonolites.

As phenocrysts appear large and much cracked leucites, green augites, a few fair-sized crystals of orthoclase much broken and corroded, which are usually associated with the augite and appear to belong to the same period of crystallization, and finally a a few remains of biotite crystals altered as usual to a granular mass of augite and magnetite. The interior of one of these last contains fine parallel straight lines of minute magnetite grains lying at an angle of about 60° with the basal plane.

The leucitites described by Klein agree on the whole so closely with the above that it is needless to do more than refer to them. Analysis No. 8, page 565, of the leucitite of Sassi Lanciati, has

been selected as typical of Ricciardi's closely agreeing analyses of this group. We may note here that they are low in silica, high in iron, lime and magnesia, and surprisingly low in alkalies, considering the amount of leucite present.

Leucite-phonolite.— Representing this group are specimens from two localities, which differ somewhat from each other and which may be described separately.

Two, from above St. Trinita near Orvieto, are from different parts of the same flow, one being compact while the other is highly vesicular, though not enough so to be a true scoria. The groundmass is light gray and in it lie many large, sharp leucite crystals up to $1^{cm}.5$ in diameter, of a pale yellowish white color and waxy luster. They are much cracked and contain large inclusions of augite and magnetite, generally as a nucleus in the center. Lining the sharp trapezohedral cavities left by leucites which have fallen out is a thin white crust, which under a lens is seen to be minutely mammillary.

In thin section the large leucites, which have generally lost much of their substance through cracking and falling out, show quite strong double refraction. The edges of their sections are sometimes corroded, and in these places one observes that they are separated from the groundmass by a narrow border of clear colorless substance, with a refractive index slightly higher than that of the leucite. This is the white crust just mentioned. Between crossed nicols it shows weak double refraction, and in places a radially fibrous, spherulitic structure is developed, the fibers diverging toward the leucite. Definite determination could not be made, but it is probable that this border consists essentially of orthoclase, perhaps due to a solution of the leucite in the magma.[1]

The green ægirine-augite phenocrysts are somewhat fragmentary. They show distinct pleochroism; $\mathfrak{c}$ slightly bluish green, $\mathfrak{a}$ light yellowish green. A very few orthoclase and one or two labradorite phenocrysts are present.

[1] It may be noted that in a leucite-phonolite from Latéra Bucca (p. 27) observed an apparent formation of leucite out of orthoclase, while in that from Acquapendente he notes the reverse process.

The groundmass is rather trachytic in character, as many orthoclase laths — best seen with crossed nicols — are present, showing decided flow structure. With them are numerous small leucite crystals, with rounded outlines, containing a few sporadic inclusions and an abundance of prismatic microlites of ægirine-augite, with $\mathfrak{c} \wedge c = 38°$. Some magnetite is also present. All these small crystals lie in a colorless base of low refractive index, which in many places shows weak double refraction, and which treatment with acid proves to be nepheline.

The other specimen of leucite-phonolite is from the large quarries immediately to the north of Bagnorea, east of the lake, whence the slabs are exported for paving stones. The same rock is described by Bucca,[1] who does not mention nepheline, though he speaks of the base as easily gelatinizable and rich in soda. It is ash gray and fine-grained, with rough texture and small cavities whose walls bear leucite but no nepheline crystals. The specific gravity was found to be 2.648 at 27° C.

Examined under the microscope the leucites and pleochroic ægirine-augites show no specially noteworthy features. The few well-shaped orthoclase phenocrysts often carry a mantle of later alkali feldspar substance like that previously described. There are also a few biotite phenocrysts which have been entirely altered to augite and magnetite in the usual way.

In the groundmass there are abundant small leucites almost free from inclusions, stout ægirine needles and some magnetite grains. Orthoclase laths are larger and more abundant than in the rock just described, and there are a few flakes of brown biotite which are among the last products of crystallization. These lie in a nepheline base similar to that of the last rock.

Klein describes a leucite-phonolite from Gradoli, northwest of the lake. Its megascopic appearance is that of a phonolite. In thin sections appear as phenocrysts a green pleochroic augite (probably ægirine-augite), some large leucites and a few sanidines. In the holocrystalline groundmass nepheline, leucite and

[1] BUCCA, op. cit., 20. Also Boll. Com. Geol. Ital., XIX, 58, 1888.

sanidine occur in well-formed crystals, along with biotite, magnetite and apatite. A little haüyne occurs, but augite is not spoken of as present in the groundmass. There is unfortunately no analysis of this rock. Klein describes also two rocks which may belong here, one from La Canonica and one from Proceno. The former is apparently a transition type towards the leucitites, the latter is noteworthy as containing haüyne and also a very basic plagioclase. Its high percentage of silica and low lime and magnesia are also remarkable (anal. 10, page 565).

The "leucitophyr" of vom Rath[1] is probably a leucite-phonolite since he mentions a colorless weakly refracting mineral as the last product of crystallization. He thinks this may be feldspar but it answers to the characters of nepheline. All of the leucitic-trachytes as well as some of the leucitophyrs, described by Bucca, probably belong here. This is shown by their augite being pleochroic, the frequent presence of haüyne, and the presence in the groundmass of a "colorless glassy base," rich in soda and easily gelatinizable (*op. cit.*, p. 19).

I may add that a specimen from Acquapendente in the collection of Yale University closely resembles my specimen, gives abundant gelatinous silica with acids, and is apparently identical with one from that locality described by Bucca. According to Scrope,[2] and apparently also according to Ricciardi[3] the lavas of Acquapendente are connected with the volcanic center of Radicofani to the north.

Leucite-trachyte proper is not definitely known from this region, though possibly one or two of Bucca's rocks belong here.

Leucite-tephrite.—Rocks belonging to this group are very abundant, and transition forms to the other types are common. Of my specimens only a few will be described in detail, as Klein's descriptions cover the ground very fully. The rocks of this group are generally of quite basaltic appearance, and resem-

[1] VOM RATH, op. cit., 290.

[2] SCROPE, Volcanoes, London, 1862, 354.

[3] RICCIARDI, Terreni Vulcanici, Florence, 1879, 133.

ble much the leucitites megascopically, though leucite is less common as phenocrysts than augite. Their microstructure is quite different and generally doleritic. The silica percentage is about 52.

The rock from Monte Cavallo south of Orvieto, a flow with columnar structure mentioned by vom Rath, and that from Porano, southwest of Orvieto, a flow which Verri considers as belonging to the Monte Rado center, are dark gray, fine-grained rocks showing few phenocrysts, and these small and entirely of dark green augite. Its specific gravity is 2.763 at 26° C.

Under the microscope they show a doleritic structure. In the groundmass leucite predominates as irregularly shaped crystals and patches, which correspond in function to the augite of ophitic diabase. It shows weak double refraction, with the usual polysynthetic twinning, and containing few inclusions of glass and augite. Lying between or imbedded in the leucites are long prisms of augite, together with plagioclase laths whose extinctions correspond to those of a basic labradorite. Some magnetite is also present, as well as a small amount of colorless glass. A few orthoclase laths were seen, but no nepheline could be detected.

The augite is grayish green, and shows an extinction angle of 41° with the axis *c*. Associated with it is a clear brown mineral, occurring here and there on the ends and sides of the augite crystals, and in small quantity as separate individuals of a somewhat fragmentary character, which show few crystal planes. When occurring with the augite the two are not separated sharply but shade into one another, the green color gradually giving place to the brown, the cracks running uninterruptedly through both. The mineral has a slightly lower refractive index than the augite, but strong pleochroism; parallel to *c* (assuming this to correspond to the vertical axis of the augite) it is dark hair brown, and at right angles to this, light yellowish brown and pale greenish yellow. The extinction angle with the cleavage cracks, which are quite well marked, reaches 17°.

These characters made it seem probable that we have here a growth of acmite about augite, as the last stage of pyroxenic crystallization. Further examination, however, showed that the bisectrix nearest the vertical axis is not $\mathfrak{a}$, as is acmite, but that of least elasticity $\mathfrak{c}$. The greater number of crystals are cut more or less nearly parallel to the vertical axis, but search revealed a few cases of parallel growth where the augite and the brown mineral were cut horizontally. In these the cleavage cracks of the augite formed an angle of 88°, while those of the external brown mineral formed angles of 122° with each other, the planes *b* (010) and *m* (110) being present, and the direction of least absorption being parallel to the clinopinacoid. The mineral is therefore an amphibole and may be referred to barkevikite, with whose characters it closely agrees. It is regretted that a chemical examination of this interesting mineral could not be made, but the small amount of the substance and its intimate association with the augite, rendered a mechanical separation impossible.

Bucca[1] mentions a brown pleochroic hornblende associated with the augite of a leucite-tephrite (?) from Poggio Pilato near Valentano, and also a similar amphibole in a leucite-trachyte from Casaccia on Lake Vico.[2] According to de Stefani[3] Rosenbusch observed a mineral like that described above in the "basalt" of Radicofani. Rosenbusch[4] also notes a brown hornblende surrounding augite in an Ischian trachyte.

It may be mentioned that since the chemical character of the amphibole pointed to the pyroxene being a soda-rich ægirine-augite, an examination was made to determine the character of the bisectrices of the latter. This showed that the bisectrix nearest the vertical axis was $\mathfrak{c}$, so that it is an augite.

Another leucite-tephrite from below Sta. Trinità near Orvieto may be the same as that mentioned by Klein from this locality.

[1] Op. cit., 28.

[2] Bucca, Boll. Com. Geol. Ital., 60, 1888.

[3] De Stefani, Boll. Com. Ital., 224, 1888.

[4] Rosenbusch, Mikr. Phys., II, 584, 1887.

It resembles the preceding, though it is much finer grained, and the leucite is seen to be quite subordinate in amount as compared with the augite and plagioclase. This last is quite basic and is a true bytownite.[1] Quite noticeable in the sections are many small flakes of brown biotite, which have given rise to patches of a bright green, finely-granular viridite, probably through atmospheric alteration. None of the other minerals show signs of decomposition, except the magnetite, which is sometimes accompanied by spots of limonite and bright orange hematite. The augite is pale gray and none of the brown hornblende is present.

Most of the leucite-tephrites described by Klein seem to resemble the above and call for no special notice. Exception must be made for those from Montalto, southwest of the lake, which Verri regards as a distinct eruptive center. They approach augite-andesites in character, but carry olivine phenocrysts, and small leucites only in the groundmass, so that Klein calls them "leucite-tephrites with accessory olivine." In mineralogical composition they correspond to a leucite-basanite, but their high content of silica allies them with the tephrites. (*Cf.* anal. 11, page 565.)

The phenocrysts are of green augite, a basic plagioclase, magmatically altered biotite, olivine, magnetite and apatite. The groundmass is andesitic in structure and consists largely of plagioclase laths, augite crystals and magnetite grains, with small colorless spots which were identified with leucite. All these lie in a glass base. It is noteworthy that in one very glassy specimen no leucite was to be found, while the other minerals remained as before.

Leucite-basanite.—None of my specimens belong here, so I may briefly mention some described by Klein as "leucite rocks of doleritic habit." All his specimens come from the southern part of the region. They are distinguished from the true tephrites by their constant olivine content and structure, and Ric-

[1] ROSENBUSCH (Mikr. Phys. II, 762, 1887) mentions the occurrence of acid plagioclase in a leucite-tephrite from "Orvieto."

TABLE I.

	1	2	3*	4	5	6	7	8	9	10†	11	12	13
SiO_2 . .	59.22	57.97	58.21	60.03	63.26	56.32	56.42	48.89	55.10	59.69	55.11	52.16	48.09
Al_2O_3 .	18.56	17.65	19.90	17.05	16.05	18.17	16.81	16.05	19.20	16.22	16.07	15.03	13.60
Fe_2O_3 .	....	0.63	4.07	1.83	1.04	2.23	3.26	1.80	....	1.93	3.04	3.17	2.52
FeO . . .	6.06	7.50	0.87	4.15	6.13	6.47	6.92	10.09	6.86	8.17	8.46	8.42	9.36
MnO . .	....	0.09	....	0.09	0.14	....	0.23	0.43	....	0.44	....	0.24	0.10
MgO . .	1.12	1.71	0.98	1.12	1.29	2.84	3.50	3.98	1.18	2.72	3.10	4.69	6.75
CaO . . .	2.96	5.53	3.58	6.58	5.50	5.33	5.64	11.88	3.75	4.80	6.46	10.07	13.05
Na_2O . .	4.87	1.50	2.57	2.31	1.62	1.80	1.21	1.81	2.68	1.03	1.58	2.38	1.41
K_2O . . .	6.66	5.31	9.17	5.12	3.18	4.18	3.07	3.00	10.78	3.09	5.07	2.47	3.07
P_2O_5 . .	....	0.42	....	0.42	0.51	0.34	1.08	0.29	....	trace	0.75	1.15	0.41
SO_3 . . .	....	....	....	....	....	....	....	0.59	....	0.64	....	....	....
Ignit. . .	1.14	1.82	0.74	1.42	1.57	2.15	2.25	1.39	1.22	1.54	0.89	0.72	1.62
	100.59	100.13	100.09	100.12	100.29	99.83	100.39	100.19	100.77	100.27	100.53	100.50	99.98
Sp. Gr.	2.55	2.45	....	2.54	2.42	2.52	2.63	....	2.50	....	2.55	2.75	2.76

* Contains trace of TiO_2.

† Contains trace of Cl.

1. Vulsinite, Nassini's quarry, Bolsena, vom Rath, op. cit., 291.
2. Vulsinite, Bolsena, Ricciardi, Klein, op. cit., 8.
3. Vulsinite, Bolsena, No. 665, Washington.
4. Vulsinite, San Magno, Ricciardi, Klein, op. cit., 10.
5. Vulsinite (?), San Lorenzo, Ricciardi, Klein, op. cit., 3.
6. "Andesitic Trachyte," Monte Alfina, Ricciardi, Klein, op. cit., 7.
7. Augite-andesite, Monte Rado, Ricciardi, Klein, op. cit., 33.
8. Leucitite, Sassi Lanciati, mean of two, Ricciardi, Klein, op. cit., 20.
9. Leucite-phonolite (?), Nassini quarry, Bolsena, vom Rath, op. cit., 290.
10. Leucite-phonolite (?), Proceno, Ricciardi, Klein, op. cit., 26.
11. Leucite-tephrite, Montalto, Ricciardi, Klein, op. cit., 28.
12. Leucite-tephrite, Monte Bisenzio, Ricciardi, Klein, op. cit., 19.
13. Leucite-basanite, Valentano, Ricciardi, Klein, op. cit., 23.

ciardi's analyses show them to be very basic, with about 48–49 per cent. of silica.

According to Klein they are gray, medium-grained rocks, somewhat vesicular. Leucite, augite and olivine appear as phenocrysts; plagioclase is subordinate in amount both as phenocrysts and in the groundmass. Klein remarks that as olivine increases plagioclase decreases, though this relation has apparently no influence on the structure. The groundmass is made up largely of augite, with leucite, magnetite and plagioclase, occasionally biotite and haüyne, and in one instance nepheline. The presence of a glass base is not mentioned.

Chemical composition.—A selection of what seems to be the best and most typical of Ricciardi's analyses is given in the table, together with the two of vom Rath. No. 3 was made by myself in the Mineralogical-Petrographical Laboratory of Yale University, with the assistance of Professor L. V. Pirsson. I gladly take this opportunity of expressing my sincere thanks to him for his valuable assistance and advice. The general discussion of the analyses will be reserved for the final paper of the series.

HENRY S. WASHINGTON

DRAINAGE MODIFICATIONS AND THEIR INTERPRETATION.[1]

CONTENTS.

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PART I. PRINCIPLES OF DRAINAGE MODIFICATION.

(1) RELATION OF DRAINAGE FORMS TO LAND FORMS.

THE great advancement in the interpretations of physiographic forms which has marked the last decade has led to a better understanding of the late geologic history of certain continental areas than has ever been attained from the study of the sediments deposited around their margin. Although such important results have been derived from this study in so short a time, they are but scattering chapters in the complex history of continental development, and much yet remains to be done before a clear insight can be obtained into the various conditions of the past. Our success in reading this history lies in following out all of the lines of corroborative evidence available, in the hope that where the evidence along any one line is weak, that along another may be strong and complete, enabling us to build up a more or less perfect whole from the different classes of facts.

The process of erosion, according to Gilbert,[1] consists of three parts: weathering, transportation, and corrasion; and is modified by three conditions: declivity, character of rock, and climate. Physiographic forms resulting from the process of erosion are necessarily modified by any change in the above mentioned causes and conditions. But since streams are the principal agents in transportation and corrasion; and since transportation and corrasion are dependent upon weathering (which is modified by climate), declivity, and character of rock, it follows that any change in the causes or conditions affecting erosion will modify the action of the streams and any modification of the action of the streams will tend to change their alignment in accordance with the changed conditions.

This intimate relation between stream alignment and physiographic forms suggests the advisability of thorough study of drainage systems, in the hope of finding some record of past conditions which will throw additional light on the question of the physiographic history of continental areas.

[1] Geology of the Henry Mountains.

(2) CLASSES OF DRAINAGE ADJUSTMENTS.

Neglecting the catastrophic effects of glaciation and volcanic action, drainage modifications may be divided into three classes: (1) Changes marking the progress of a river through a normal cycle of development. (2) Adjustments due to character of rocks and geologic structure. (3) Rearrangements caused by local uplifts or depressions of the earth's crust.

Class 1. Changes during the normal development of a stream.— The modifications falling within this class are well understood, having been thoroughly worked out by Davis and others, but for the sake of clearness will be briefly restated.

A cycle in river development, according to Davis,[1] consists of the interval of time during which a river reduces the land within its watershed to baselevel. Let us for a moment glance at the process by which this is accomplished. In its youth the grade of the stream is necessarily great, since the surface of the land must be far above baselevel. With a steep gradient the current is everywhere rapid, and all of the refuse worn from the land by weathering and corrasion is carried by the force of the current into the sea. The stream so loaded becomes an abrading instrument of great power, and its channel soon partakes of the character of a rocky gorge or canyon. That portion of its course which is nearest the mouth of the stream will first be reduced approximately to the baselevel of erosion. As soon as that is accomplished the gradient becomes so low that the stream can no longer carry its burden of waste to the sea. A portion of its load will be dropped in the channel deflecting the current from its original course and causing it to cut away its banks on the side toward which the current sets. As the current is lessened by these meanders, its carrying power is diminished and it is forced to give up more of its load which is added to the barrier already existing and which tends continually to deflect the stream into broader and broader meanders. Thus in progressing from youth to old age, the stream changes its appearance in accordance with the changed conditions which surround it. Conse-

[1] The Rivers and Valleys of Pennsylvania, Nat'l. Geog. Mag., Vol. I, p. 203.

quently the history of this portion of the cycle is recorded, not alone in the sculptured forms of the land, but also in the changed alignment of the streams.

As the stream approaches extreme old age, its gradient grows less and less, and the divides between adjacent streams become so low that many adjustments are required before a perfect balance prevails between the contending streams. This is due to the fact that in this portion of the cycle the streams are but slightly prepared to defend themselves, and any stream handicapped by a circuitous route to the sea will eventually suffer loss of drainage area at the hands of a neighboring stream.

It would be almost impossible to read the history of drainage developments, unless we could go back for our beginning to some period in which drainage conditions are known. During its period of youthful development, a stream leaves but few traces by which, in after years, we may judge of the extent of its drainage basin, or of the conditions under which it labored; during its maturity its records are equally unintelligible, for they tell us nothing of the local conditions which surrounded it; but in its old age we can say with confidence that, so far as it is untrammeled by local obstacles (and local obstacles are rare in this stage of erosion), it is evenly balanced against the surrounding streams. If then we find traces of a stream having reached old age, we can calculate with reasonable certainty the extent of its basin, or if its basin does not extend to the limit which should mark the contending streams, we may be assured that local obstacles interfered with its normal development. Thus the last stage of the life history of a river implies certain physical conditions, consequently it is the period to which we must refer in undertaking to read the history of drainage developments.

Class 2. Adjustments due to rock character and geologic structure. — Drainage modifications which fall within this class have received the attention of our ablest physiographers, hence their mode of origin is well understood. Gilbert has shown how streams, flowing on inclined beds of alternating hard and soft

rock, will naturally tend to migrate down the slope of the beds, producing a change in the alignment of the streams. Davis has fully demonstrated that streams flowing over folded and faulted rocks will first have their positions determined by the synclinal folds of the structural surface, and then they will migrate to the anticlines, or in technical terms will change from consequent to subsequent streams.

Changes due to these conditions are of great importance in drainage studies, but, since complicated geologic structure is limited to small areas compared with the continental mass, such conditions can prevail only in a prescribed area, and consequently affect but a limited number of streams. Hence in a general study of drainage changes, this class does not deserve the prominence that has been attached to it.

Class 3. Rearrangements caused by radial crustal movements.— If the earth's crust remained entirely free from movement, the history of the drainage would be extremely simple, consisting of but a single cycle; and its barrenness of striking features would only be equaled by the monotonous expanse of baseleveled plain which would be produced during the cycle. The present diversity of surface features is positive evidence that such has not been the case — that the crust of the earth has suffered repeated oscillations which have prevented the formation of such an extensive baseleveled plain, and at the same time have complicated the drainage history to a remarkable extent.

Recent studies of the Mesozoic and Cenozoic peneplains of the southern Appalachians seem to demonstrate that this region has suffered two kinds of crustal movements in post-Palæozoic time. Both of these come under the class of radial movements, but they differ in the intensity of the deformation of the baselevel and in their lateral extent. For convenience of study we may divide them into general and local oscillations. As the name implies, the first class embraces those movements of elevation or depression which are of continental or semi-continental extent. Since the amount of movement is slight compared with the horizontal extent, the deformation will be so slight as to be

unrecognizable. These movements may produce a complete transformation of the drainage features of a land area by causing a portion of it to be depressed below drainage level; or they may cause the revival, or rejuvenation of the streams by lifting the land above its previous position. In any case the modifications arising from such movements will fall under the first class, or those due to the natural course of events in a normal cycle of development.

Crustal movements of the second, or local class affect but a limited area. They consist of uplifts or depressions which reach a maximum along an axial line, grading off to the undisturbed strata at no great distance on either side. The local movements which have occurred in the past have not generally been intense enough to cause a perceptible dip of the rocks, but they have elevated the surface into broad ridges, or depressed it into shallow troughs.

The effects of these local movements upon the drainage must have been very different from the general movements. They would cause no general revival, but would affect the streams locally, and consequently their effect in producing rearrangement must have been very much more potent. The principal object of this paper is to study the effect of these local movements upon the streams; to endeavor to establish the criteria by which the changes due to this influence may be recognized; and lastly to apply these criteria to a continental area, and by their assistance endeavor to read the history of the region in question.

(3) IDEAL CASES ILLUSTRATING THE EFFECT OF LOCAL EARTH MOVEMENTS.

In studying this subject in the field, the observer is frequently confused by local conditions of geologic structure and alternation of hard and soft strata, which apparently overshadow the more subtle influence of crustal warpings; although the latter may, in a general way, be the dominating force which has shaped the drainage systems. In a theoretical consideration of

the question, however, we can eliminate the local disturbing conditions and thus determine the true value of surface warpings as stream modifiers.

We will then assume a land area in which the strata are horizontal and perfectly homogeneous and, for farther simplification, will suppose that its surface has a regular descent from a low, interior water-parting toward the sea on either side. If in such an area the climatic conditions are the same on either side of the dividing ridge, the rate of erosion would be the same and the opposing streams would be held in a delicate balance against each other. The amount of energy expended by one stream in corrading its channel would necessarily be the same as that of its antagonist and the gradient of the streams, in their various portions, would show a close correspondence.

(*a*) *Effects of elevation.*—If then an uplift should occur across one stream a short distance from the divide, it would not materially change the ratio of energy expended by the streams in the corrasion of their channels; each would be increased by the increased gradient, but the energies would be expended in very different portions of the channels. The stream which is not crossed by the axis of uplift would have its gradient near headwaters increased, and consequently the greater portion of its corrasive energy would be concentrated upon the divide at its head. The stream which is crossed by the axial line would have its gradient near headwaters diminished, while below that line its gradient would be increased, consequently a large amount of its energy would be transferred to that part of its course which is below the axis of uplift, and almost none would be used on the divide against which its antagonist is concentrating all of its force. There can be only one result, and that is the gradual eating away of the divide on the side opposite the uplift, and the consequent migration of this divide toward the axis of elevation. It matters not how slow nor how slight is this uplift, its effect will be the same in character, though differing in amount of modification produced. The principle is fundamental and must apply in all cases.

Figures 1 to 4 are a graphic representation of the manner in which such an uplift would affect the drainage and cause the divide to migrate towards its axis. Let *A*, *E* (Fig. 1) represent a

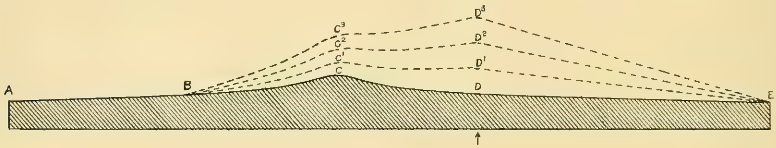

FIG. 1.

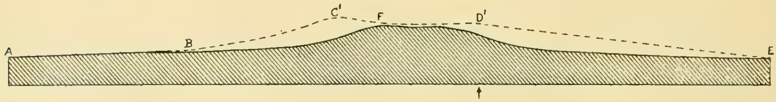

FIG. 2.

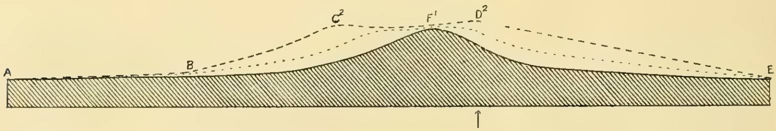

FIG. 3.

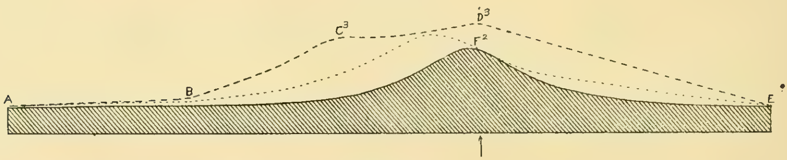

FIG. 4.

cross-section through the divide *C* separating two streams flowing in opposite directions, the profiles of which are represented by the curved lines *A*, *B*, *C* and *E*, *D*, *C*. Let us suppose still farther that the streams are balanced against each other, consequently the profile will be symmetrical. It is evident that the divide *C* will remain stationary unless some external cause interferes to disturb the delicate balance now maintained. Suppose that such an external cause elevates the strata at the point *D*. Since we are dealing with the effect of local movements, we will suppose that this movement extends each way only so far as the points *E* and *B*. Now if the point *D* were elevated by the force

represented by the arrow, it would take successively the positions D^1, D^2, and D^3, and the divide C, if it remain stationary, would occupy the positions C^1, C^2 and C^3. If the movement were sufficiently rapid, so that erosion produced no sensible effect, it is obvious that when the point D reached D^3, it would be at a greater altitude than C^3, and consequently the divide would be shifted from C to D; thus the stream flowing toward E would be beheaded and the stream flowing toward A would be increased by the beheaded portion.

It is not at all probable that the great majority of crustal movements are rapid enough to produce this effect. Let us examine the problem and see if a slower rate of elevation would affect the drainage.

Suppose that the rate of elevation is but little more than the rate of erosion. Under the supposition the condition of the divide would be represented approximately by Figs. 2, 3, and 4. Generally the first result of the uplift is the formation of a barrier at the point D, but if the rate of movement is very slow and the rocks soft, the stream may cut away this barrier as fast as it is produced by the upward movement. The rising of the land and the cutting of the stream continue until the elevation reaches D^1; at that period of development the condition of the streams and the divides is shown in Fig. 2. The original surface is represented by the broken line, A, B, C^1, D^1, E. According to our assumption, the streams were nicely balanced against each other before the uplift occurred, hence the slightest elevation at D would raise a barrier in the pathway of the stream C, D, E, and while this stream may be able to remove the barrier, it involves a certain expenditure of time and energy which the stream A, B, C, is not required to make. Thus the effect of such a barrier is to retard the stream which it crosses, but in the case under consideration the uplift not only retards one stream, but it steepens the grade of the other and consequently accelerates its corrasive power near headwaters.

Under such favorable conditions, it would cut rapidly into the divide at C while the other stream is expending its energy in

keeping its channel free at the point *D*. The actual amount of corrasion accomplished by the two streams is probably not far from the same. The stream *A*, *B*, *C*, is accelerated greatly, but this acceleration is limited to its headwaters where its volume of water is small, hence its power of corrasion is not proportionately increased: on the other hand the stream *E*, *D*, *C*, is retarded at its headwaters, but accelerated in its lower course, and since its volume of water is greater at the point of acceleration, its power of corrasion is considerably increased, although its gradient is but slightly changed. This transfer of active corrasion from *C* to *D* is what weakens the stream *E*, *D*, *C*, and gives the stream *A*, *B*, *C*, its great advantage; for nearly all of the cutting of the latter stream is confined to the immediate vicinity of the gap. When the point *D* is elevated to D^1 the profile of the streams will be *A*, *B*, *F*, *E*, instead of *A*, *B*, *C*, *D*, *E*, and the divide will have migrated from *C* to *F*.

This process is continued as the point *D* is elevated. When it reaches D^2 (Fig. 3) the stream *E*, *F* will have been so handicapped by the uplift across its course and the stream *A*, *B*, *F*, so accelerated by the same movement that the divide will have migrated still further toward the axis of uplift and will occupy some such position as F^1. Again the uplift continues and the point *D* reaches D^3, and the divide F^1 reaches the position F^2.

The figures (1 to 4) would seem to indicate that the rate of migration is the same for a given amount of elevation whether the divide is near or far from the axis of uplift. Such can hardly be the case, for if the axis crosses the stream at some distance from its source it will be at a point where the gradient of the channel is less than if the axis were near the headwaters of the stream; consequently the stream which is retarded will suffer most at the first uplift and as a consequence the divide will tend to migrate rapidly. Later uplifts will occur at points where the gradient is steep and consequently they will have but little effect. In the case of the stream which is accelerated, the tendency will be different. At the beginning of the uplift the drainage basin is so far removed from the axis of the uplift that

its effects are somewhat feeble; but as the divide migrates toward the axial line the acceleration of the stream will become greater and its most effective work will be accomplished when the divide approaches close to the axis of elevation. In balancing the two processes, it seems probable that the former is the controlling element and that the divide migrates more and more slowly as it approaches the axis; and the duration of the last stage may be many times that of the first.

If the uplift continues indefinitely the divide will certainly reach the axis and there it will remain so long as the uplift continues, unless some more potent force causes it to change.

Under the last assumption the rate of the uplift is, at least, equal to the rate of corrasion. We must now consider the case when it is much less. This probably approaches more nearly the actual condition which has accompanied each movement in this province. Since the rate of elevation is less than that of corrasion, the streams can more than keep pace with the rising fold, and hence their profiles will change only in a nearer approach to baselevel and the migration of the divide toward the axis of uplift. The conditions remain practically the same as in the previous case, except that now the divides will migrate more slowly and will constantly approach baselevel.

If the axis of uplift corresponds with the original divide (Fig. 1), there will be no migration, for each stream will be accelerated equally, and each will concentrate its energies at the same point — the divide *C*. The position of the divide *C* will be maintained as long as the uplift continues, unless some external cause exerts a more powerful influence in an opposing direction.

(*b*) *Effects of depression.*— As we have already seen, any pronounced tilting of the surface of the earth tends to produce a migration of the divides in the region affected by the tilt, hence the principle of the migration of divides will apply equally well whether the movement be elevation or depression. And while in the great majority of cases of earth movements the effect is to elevate the land, there are well-marked cases of local

subsidences in the Appalachian province ; and it is well to consider the case in detail so as to familiarize ourselves with the phenomena which it produces.

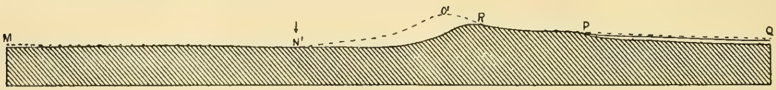

FIG. 5.

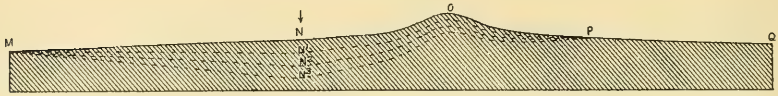

FIG. 6.

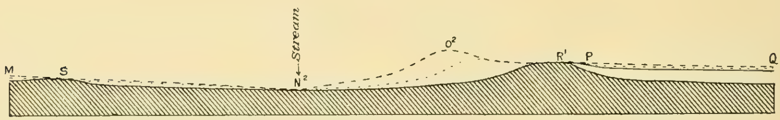

FIG. 7.

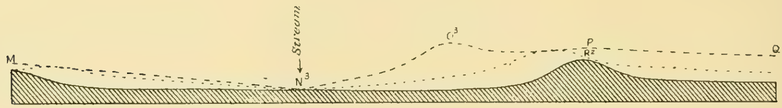

FIG. 8.

Starting with the assumption of two streams, M, N, O and Q, P, O (Fig. 5), equally balanced against each other, we will suppose a subsidence to occur at the point N, causing it to assume in successive order the position N^1, N^2 and N^3. It is obvious that if the depression is more rapid than the corrasion of the stream on either side of the depression, the stream will become ponded at the point N, and will, in all probability, seek an outlet at right angles to its former course and approximately along the axis of subsidence. If, on the other hand, the movement is so slow that erosion can keep pace with the depression the change will not be so radical, but in the end will result in approximately the same arrangement as sketched for the former case. It will be accomplished about as follows: In the first stage of the

movement, when *N* is depressed to N^1, the stream *M*, *N*, *O* will have been seriously retarded by the decreased gradient of that portion of its upper course which is within the limits of the crustal movement. In this first stage, as shown by Fig. 6, the stream has lost almost all of its gradient, and corrasion along the lower course of the stream has not been able to relieve the sluggish portion of its upper course. It is incorrect to consider the entire upper course as retarded; the portion below the axis of depression, or that portion which is tilted toward the head of the stream, is rendered sluggish; but that portion which is above the axis is considerably accelerated by the downward tilting and the stream will corrade its channel back into the former divide. The stream *Q*, *P*, *O* will suffer by the depression of its headwaters, and so will be deprived of the power to hold its own against the opposing stream. As in the cases already discussed this divide will migrate toward the weaker stream, or away from the axis of depression.

If the subsidence continues, the point *N* will soon be lower than the stream channel farther down, and consequently ponding will ensue, until the ponding waters can find an outlet in some other direction. This is supposed to have occurred in Fig. 7, and a transverse stream is located at the point where the axis crosses the course of the former stream. A new divide is thus formed between *M* and *N*, its position depending upon the readiness with which the waters find an outlet at *N*. On the other hand, the divide *R* will have migrated to R^1. In the last stage the divide *S* will have reached *M* and the divide R^1 reached R^2.

In comparing the results obtained when the movement is depression with those produced by elevation, it will be found that the changes are of the same character whether the movement is elevation or depression, or whether it is fast or slow. In all cases the divides will tend to migrate up the slope of the tilted surface, and they will so continue until the point is reached where the surface is unaffected, or else is inclined in another direction.

In the cases so far considered we have assumed that the process continues to its completion—that the uplift or depression was of such duration that the streams became perfectly adjusted to their changed conditions, and that the divides in all cases reached the highest point on the tilted surface. This is the ideal condition, but in reality it is probable that the movements were seldom of sufficient duration to produce this result. Hence in applying these principles in the field we must expect to find cases where the migration was but partial and the streams continue to head across the former axis of uplift. Also we have, in the foregoing cases, assumed the simplest conditions possible. Nowhere in actual practice will the physiographer have to deal with so simple a case as we have here assumed; he will find instead of homogeneous rocks a mass of alternating sandstone, shale and limestone which will greatly modify the results, and he will find complex geologic structure instead of the horizontal rocks in the ideal case. While the actual conditions in the field seem so different from those which we have assumed, the determination of the ideal case furnishes us with a law which applies to all cases, but under complex conditions its results are difficult to distinguish from those produced by other forces.

(4) LAW OF THE MIGRATION OF DIVIDES.

Whenever local radial movements occur in any region the stream divides in that area will tend to migrate; the direction in which they move will be determined by the character of the crustal movement; and the extent of the migration will depend upon the amount of movement and the local obstacles which the streams may encounter. If the movement is upward the divide will tend to migrate toward the axis of uplift; and if the movement continues long enough, and other conditions are favorable, it will reach the axial line and there remain. If the axis coincides with a divide already established it will hold the latter stationary, unless some stronger influence causes it to migrate.

If the movement is one of subsidence the divide will tend

to migrate away from its axis; and will continue in that direction until the streams attain a condition of equilibrium.

The migration of the divide away from the axis of depression generally results in the formation of a stream along the axial line; and the direction in which it flows will depend, in a great measure, upon the pitch of the axis of the fold.

Such is the law of the migration of divides, under the influence of surface warpings. It is probable that if such migrations have occurred in the past we can find some trace of the modifications thus produced and be able to determine the character, direction and extent of the movements, and from that form some idea of the physical condition of the continent in late periods of geologic history.[1]

MARIUS R. CAMPBELL.

U. S. GEOLOGICAL SURVEY.

[1] To be followed by Part II, Criteria for Determining Stream Modifications.

GLACIAL STUDIES IN GREENLAND. IX.

WITH one exception — the Igloodahomyne — the glaciers thus far studied have been dependencies of local ice-caps. Those first sketched were connected with the snow fields of the island of Disco. Those which we have just been considering were offsprings of the snow-cap of the Redcliff peninsula. We are now about to turn to the tongues, lobes and border of the great ice mantle of Greenland.

The order of study we have pursued has certain elements of advantage that may be noted before we pass on, as it may be helpful in giving significance to our further observations. The local glaciers of Disco were found to present sloping borders, after the usual style of southern glaciers. It would appear that this mode of termination is the dominant habit of the glacial border in southern Greenland, but I was not permitted to make observations which justify me in asserting this, and the writings of others do not seem to be sufficiently specific on this point to warrant an unqualified affirmation. The glaciers of Disco have much the same limitations in size as the glaciers of southern alpine regions, and this may possibly give occasion for the inference that the element of magnitude is a controlling one in determining the marginal habit of a glacier. In view of this possible appeal to magnitude as an element of interpretation, it is fortunate that we have been able to study glaciers of like dimensions in high latitudes. It may be safely inferred, therefore, that the differences in the verticality of the glacial margin, which we have found so pronounced, and in the basal stratification (if this difference really exists) are not functions of magnitude.

In like manner it is of some importance to know whether the differences in the magnitude of the glaciers of the northern field, when compared with each other, are correlated with any impor-

tant variation in the mode of their deployment. If it shall appear that there are no essential differences between the action of small ice-caps and large ones, an important gain to interpretational methods will have been realized; for, if magnitude does not constitute an important source of difference in mode of action in high latitudes, it probably does not in low latitudes, where only small glaciers exist and comparisons in magnitude are impossible beyond the narrowest limits. In so far as a comparison of the foregoing small ice-caps and their dependencies with the great ice-cap and its dependencies, yet to be described, contributes to the adjudication of the element of magnitude as a factor in glaciation it subserves a function to which few contributions have been possible heretofore.

It will of course not be overlooked that there is an important distinction between the small glaciers which we have just studied and the small alpine glaciers that have been the chief subjects of study in southern latitudes. The glaciers of Redcliff peninsula all radiate from a common ice-cap gathered upon a plateau of moderate elevation. The glaciers of like magnitude of southern latitudes hang on mountain slopes or nestle in mountain valleys. The nearest approach to an ice-cap in these regions is found in the snow fields that mantle the mountain cols. The rugged environment of the alpine glaciers has given to them a burden of superficial detritus which very much obscures their basal features and has imposed a constraint in deployment which very much distorts their normal evolution. From these restricting conditions the glaciers of the Redcliff peninsula are almost wholly free.

A special point of comparison between small and large ice-fields, of supreme importance in its bearings on the interpretation of the drift of the Ice Age, is the mode of introduction and transportation of rock débris. The small fields show us these phenomena as executed in short distances; the great fields, in long distances. The diameter of the Redcliff peninsula is not more than fifteen miles; the diameter of the great ice-cap is 700 miles, a ratio of about one to fifty. None of the material

borne out by the radiating glaciers of the Redcliff peninsula can be supposed to have been carried more than six or eight miles. Some of that borne out by the great inland sheet may have been carried three or four hundred miles.

If, in the descriptions and illustrations that follow, it shall be found that the interlamination of débris in the base of the great ice-cap is of the same nature and degree as that of the small ice-caps we have just studied, it will seem to be a safe inference that this intrusion of débris has narrow limitations in its development and is not at all proportional to the magnitude of the ice body with which it is connected. The point is one of fundamental importance, for it has a decisive bearing on the radical question whether the ratios of free to loaded ice which are found to obtain in the small glaciers can be applied to the great ones that are now extinct. If, for instance, it is found that a glacier which is no more than six or eight miles in length is well inset with débris to the height of fifty or sixty, or even one hundred feet, from its base, it might be inferred — indeed it has been inferred — that a glacier 300 or 400 miles in length might be filled to a proportional height, *i. e.*, to 2500 or 3000 or even 5000 feet. If such a law of ratios holds true, we shall find the glacial lobes and border of the main ice-cap exhibiting an interlamination and a burden of débris of a truly magnificent order.

The purpose of this discussion, at this point, is to quicken observation on the illustrations of the great ice-cap, and of its lobes and tongues, to which we now turn.

The Tuktoo glacier.— The general form and relations of the Tuktoo glacier may be best apprehended by reference to the maps opposite pp. 198 and 669 in preceding articles. It will there be seen that it is simply a lobe of the main ice-cap descending from the north to the lowland which constitutes the neck of the Redcliff peninsula. Its movement is directly opposite to that of the Krakokta glacier last described, which descends the north slope of the Redcliff plateau. These two glaciers come into direct conflict and form the most interesting joint terminal

moraine already described in connection with the Krakokta glacier (p. 836). In view of the considerations above noted, the

FIG. 60.—View of the south side of the eastern lobe of the Tuktoo glacier seen from a point on the lower slope of the Sentinel nunatak, looking northeasterly. The smooth, nearly vertical wall of the glacier is seen in the foreground with the crevasses running from left to right with an inclination forward. Crossing these in the upper part of the glacier may be seen numerous lines running from left to right obliquely upwards and backwards, and curving toward the glacial axis in measurable conformity to the configuration of the ice. At the right hand in the foreground is seen the terminal moraine mantling a base of ice, and also a portion of one of the lakelets mentioned in the text. Beyond this moraine is seen the Bowdoin glacier which is separated from the Tuktoo glacier by a depression and by the moraine just mentioned. The eminence in the background at the left is the Sierra nunatak. The eminence in the distant center is the Sugar Loaf which stands on the border of the inland ice field. The lobe obscurely seen on the right is the Mirror glacier. The moraine from which Mr. Peary took his departure on his last trip across the great ice field may be seen obscurely, perhaps, at the right of the illustration, nearly opposite the Sugar Loaf.

reader is invited to turn back to the figure on the page cited and compare at a single glance a glacial lobe of the great ice-cap and a glacial lobe of a very small ice-cap. It will be difficult to

find any essential difference between the structure, the débris burden, or the mode of action of the two glaciers. The moraine is very symmetrical and shows no preponderance of action on either side. The right-hand slope is made up of gray crystalline rock contributed by the lobe of the great ice-sheet, and the left-hand slope is made up of red sandstone contributed by the lobe of the little ice-sheet. The work of each is perfectly declared and is singularly balanced.

If from this point of junction and conflict we turn to the right and follow the border of the Tuktoo glacier, we shall find it holding aloof in a measure from the Sentinel nunatak whose base it skirts. A vertical wall faces the nunatak throughout the entire arc skirted by the glacier. At no point does the ice press hard against the sides of the mountain. On the west angle it rises somewhat on the foot slope but does not close up the fossa between the ice and the mountain.

Our first illustration (Fig. 60) is taken from the base of the nunatak looking northeasterly obliquely across the south face of the eastern lobe of the glacier. It will be seen that the vertical wall possesses the same features of interlamination of débris in the basal part, and of freedom from débris in the upper part, which has so generally characterized the glaciers previously described. The face here is the smoothest and most strictly vertical which I observed in Greenland, and the amount of interlaminated débris is notably fine in grain and small in amount. The absence of a moraine or talus slope at the base (except at the extremity) will be noted. The interlamination of detritus reaches to the height of about seventy-five feet above the base. Although an offshoot of the great ice-cap, it is to be noted that the débris does not rise higher than in the glaciers from the small Redcliff ice-cap. The amount of the included débris happens to be here somewhat less than that in most of them.

In describing the upper Blase Dale glacier of the island of Disco (p. 785, Vol. II) note was made of numerous fracture lines traversing lateral portions of the glacial surface in a direction at variance with, indeed transverse to, the normal course of

crevasses in such a position. A similar system of fracture lines is observable on the side of the Tuktoo glacier facing the Sentinel nunatak. The general nature and course of these may be made out from an inspection of Fig. 60, but the details are bet-

FIG. 61.—A nearer view of the south side of the eastern lobe of the Tuktoo glacier from a photograph by Professor Libbey, showing the verticality of the wall, the absence of a moraine at the base, the crevassing in a moderate degree, having the direction usually taken on the side of a glacier, and, particularly, the non-gaping crevices, running transverse to the crevasses.

ter seen in Fig. 61. In the upper part of the glacier it will be observed that there are numerous oblique fracture lines starting within the dark band which represents the vertical wall of the glacier and running obliquely backward and upward, curving toward the axis of the glacier. It will be seen that these cross the layers of the ice, which are shown by light and dark banding on the vertical side and by parallel ridgings on the upper surface of the glacier. The normal system of crevassing may be seen imperfectly by the gaping fissures on the side of the glacier at the left in Fig. 60. They are also indicated by the

streams that issue on the face of the glacier in the center of the figure. These follow the crevasses until they reach the face of the glacier, when they descend it vertically. (It may be remarked in passing that the whiteness of the track of these little streams as they descend the side of the glacier indicates the relative purity of the ice. The blackened, unwashed surface shows the extent to which the fine débris, when freed by slow melting, covers the surface and invites an illusive impression of its amount.) Fig. 61, from a larger photograph taken by Professor Libbey, shows more satisfactorily both the normal, gaping crevasses and these unopened crevices, and displays at once their differences in nature and in direction. By inspection of this figure it will be seen that these crevices extend to depths quite comparable to those reached by the crevasses, though they are individually less persistent. It will be observed that they usually terminate at a bedding line or at a fellow crevice and that they very much resemble the jointing of certain tilted rock beds. In some instances faulting appears to be indicated.

As remarked in the case of the upper Blase Dale glacier, the stress or tension which caused these crevices was not of such a nature as to require the gaping of the crevice after it was formed. In this respect, as well as in their direction, they differ from normal crevasses. It will perhaps be best to reserve a discussion of the cause and significance of the phenomenon until the remaining glaciers are described and the general subject of interpretations and inferences is taken up.

The two photographs show imperfectly a horizontal lining or ridging of the retreating surface of the glacier above the vertical face. These lines really represent a series of small terraces, the vertical faces of which rise a foot or so in height and the upper faces of which range up to a dozen feet in width. These terraces are really the obliquely outcropping edges of the glacial strata and are developed into the terrace form by differential melting of the ice, much as steps in stratified rock are developed by differential erosion. Their attitude is due to the upward curving of the layers of ice as they come to the surface, in accordance with

the habit of the glaciers of the region. These little terraces were so pronounced that one instinctively follows them in walking upon the upper surface of the glacier if his course lies at all coincident with them.

FIG. 62.—View of the terminal face of the Tuktoo glacier at the southeastern curve of the eastern lobe, showing the projection of the upper layers over the lower and the attendant phenomena.

An inspection of the base of the glacier as shown in Fig. 61 gives emphasis to the remark already made respecting the smallness of the débris in the ice and the absence of a lateral moraine. Following the face to the right, however, it will be seen that at a point where the border curves about to form the terminal face of the glacier, as shown in Fig. 60, there is a notable accumulation of débris in the form of a terminal moraine. This, however, is deceptively large, as the mass of the ridge is composed of ice concealed beneath a veneering of rock rubbish.

This terminal deposit extends around the extremity of the glacier to the Sierra nunatak which is seen in the background of the illustration, at the left.

The wall of the glacier, which in the foreground of the illus-

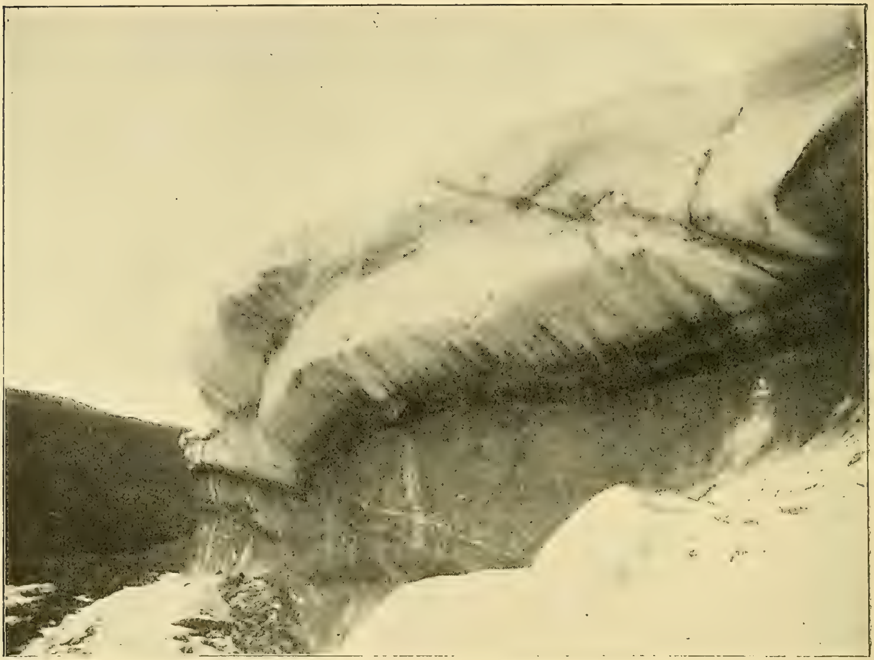

FIG. 63.—Another view of the terminal face of the Tuktoo glacier at the south-eastern curve of the eastern lobe, showing a more marked projection of the upper layers over the lower with the fluting of the under-side of the layers.

tration is so smooth and vertical, becomes irregular and overhanging at the extremity. This irregularity consists essentially in the projection of the upper layers over the lower. This over-projection reaches an extent of twelve or fifteen feet and takes on the aspects which are so well illustrated in the reproduction of photographs 62 and 63 as to leave little need for verbal description. The projecting portions consist of thick beds of nearly clear ice separated by seams of dirty ice. The phenom-

ena naturally raise the question whether the projection of the upper layers is due to actual overthrust of the upper layers or merely to the more rapid melting of the lower layers, or to a combination of the two. There is no question but that the dirty layers absorb the solar heat with more facility than the cleaner ice and are melting backward more rapidly, and that some of the irregularities which the vertical faces of this and other glaciers present are due to this differential melting. There is, on the other hand, little room for doubt that the upper layers of the glacier move faster than the lower ones. This is in accord with the generally accepted doctrine that the upper portion of a glacier moves faster than the lower, a doctrine based upon observation as well as theory. It is, however, an open question whether the differential motion is localized along the planes which separate the layers, or whether it is distributed through the mass. It is not advisable to enter at length upon the discussion of the question here, but these very striking phenomena merit special study with reference to it. It will be observed that the undersides of the projecting layers are distinctly fluted. This might easily be interpreted as a demonstration in itself of the movement of the upper layers over bowlder-shod under layers, resulting in the grooving of the over-running masses. It appears clear, however, that to some extent at least the fashioning of these flutings in the form in which they are now seen is due to the action of water descending the face of the glacier and flowing backward on the under side of the projecting layers. This does not, however, dismiss the hypothesis that the initiation of the fluting was due to differential motion between the layers. The fact that the débris has been carried in between the layers is in itself very significant respecting the hypothesis of one layer sliding over another. But this differential motion might have been confined to the point where the débris was carried in and may not be taking place in this terminal part of the ice. So this class of evidence, though it is pertinent to the general question of a shearing motion between the layers, is not altogether unequivocal in its application here.

Between the Tuktoo glacier and the Bowdoin glacier, which lies immediately east of it and runs transverse to this part of it, there is a valley in which has accumulated morainic material from both. The amount of this, however, is rather unexpectedly small when we consider the size of the two glaciers and the activity of the latter. Under this débris there is much ice and probably the two glaciers are in actual contact below it. Between the two glaciers and the adjacent nunataks there are two small lakelets of triangular outline, one lying on the right-hand side of the Tuktoo glacier, hemmed in between the two glaciers and the Sentinel nunatak, and the other on the left hand, between the two glaciers and the Sierra nunatak.

The vicinity of the nunataks afforded an opportunity to find a minimum measure of the height to which the ice formerly rose. Drift and glacial erosion were observed on the summit of the Sentinel nunatak up to a height of about 1600 feet. The extreme summit was much broken and riven and gave uncertain evidence whether it had been completely submerged or not.

T. C. Chamberlin.

STUDIES FOR STUDENTS.

DEFORMATION OF ROCKS.—IV. CLEAVAGE AND FISSILITY (*continued*), JOINTS, FAULTS, AUTOCLASTIC ROCKS.

RELATIONS OF CLEAVAGE AND FISSILITY TO OTHER STRUCTURES.

RELATIONS OF CLEAVAGE AND FISSILITY TO BEDDING.

WHERE a rock series is composed of layers of different lithological character, and is in the zone of combined fracture and flowage, the deformation includes the development both of cleavage by normal plastic flow and of fissility in the planes of shearing, in both homogeneous and heterogeneous rocks, and perhaps of all gradations between the two. The beds in the heterogeneous rock may be each approximately homogeneous. There is necessary rearrangement within the beds as well as readjustment between them. Therefore the rearrangement within the beds, in so far as it is not affected by the readjustment between the beds, will tend to produce cross cleavage and cross fissility, while the readjustment between the beds will mainly be by parallel slipping, and will tend to produce parallel cleavage and parallel fissility (Fig. 10, p. 478).

In passing from the limbs of the folds toward the crests or troughs, parallel readjustment becomes less and less important, and normal plastic flow or fracture along the shearing planes becomes more and more important. At the arches and troughs the thrust for a given bed are approximately equal, in opposite directions, and when deeply enough buried its entire thickness is under compression. The direction of least resistance is vertical. Therefore the conditions which here prevail are those of

the formation of cross cleavage and cross fissility. It follows that in heterogeneous rock strata, parallel structures may prevail on the limbs of the fold, and cross structures on the crests and in the troughs. At intervening places may be found all the complex effects of the interaction of the two (Fig. 7). In many cases where there is almost perfect accordance of primary and secondary structures on the limbs, and the rocks are so crystalline that the two cannot readily be discriminated, at the crests and troughs both structures may readily be seen intersecting each other.

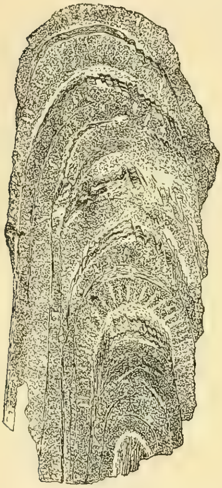

FIG. 7 (reprinted from p. 470).—Parallel fissility on the limbs of the folds and cross fissility on the anticlines, and gradations between the two. After Heim.

The deformation is mainly by folding, but on the anticlines, where the material is partly relieved from stress, the deformation is partly by the multiple minor slips of fissility.

Formations are but divisions of rock masses greater than beds which are roughly homogeneous. In each formation, considered as a whole, cross secondary structures will usually be produced, while at the contacts between the formations, where major readjustment is sure to occur, nearly parallel structures may be found. In the discussion of each separately it has been seen that in the cases of extreme folding the relations between the different secondary structures and bedding are nearly the same, and therefore that cleavage and fissility developed under each of the laws will merge together, and both be approximately parallel to the reduplicated beds. They are all brought into nearly parallel positions, just as are pebbles in the folding process. In order that this should be done, it is plain that there must be such extreme rearrangement of the rock material that it could not inaptly be compared with kneading.

In rock masses in which the alternating layers of different strength are not beds, the principles of the development of cleavage and fissility are the same as in the heterogeneous

bedded rocks. The different layers may be due to secondary structures. They may be due to the flowage of igneous material along primary or secondary planes of weakness, or to secondary water-deposited impregnations along such planes. They may be due to heterogeneous injections. In all of these cases, as in any other, the stronger beds will to a certain extent control the movements. The accommodations will occur along the layers when folded, and there will be a tendency for cleavage and fissility to develop parallel to them.

The more unequal the layers in thickness and strength, the more likely is the major accommodation to take place parallel to them, and thus produce cleavage and fissility which nearly accord with them. In proportion as the rocks approach massive ones, the law of cross structures prevails, but in a minor way readjustments along the laminæ may occur, and these laminæ still retain their integrity. In rocks as they occur in the field both tendencies are always present in all the parts, from the minute laminæ to the largest masses. Sometimes the first is predominant, sometimes the second. If the lamination is not strongly marked the first tendency will control, although the lesser layers or laminæ of unequal strength may in a minor way control the movements.

Ordinary shale is a representative of rocks having minute layers of slightly different strength. Usually the average of the cleavage or fissility distinctly cuts the beds. The material yields to thrust by flowage or fault slips combined with minute puckerings. If the process be continued far enough the individual layers are folded upon themselves in a large number of parallel folds, nearly at right angles to, or inclined to, their original positions. Therefore, while cleavage does nearly correspond with the original beds, the particles have been so much deformed and rearranged and the layers have been so far readjusted as to make the term bedding scarcely applicable.

As has been seen (p. 474), beds are particularly likely to largely control the direction of cleavage or fissility if the folds are monoclinal and overturned. In such folds the major dif-

ferential movements are along the longer limbs. Therefore the cleavage develops in a corresponding direction, being nearly parallel to the bedding on one limb of each fold and cutting across the bedding on the other, steeply inclined or overturned limb. As the area of outcrop of the steeper limbs is much less than that of the more gently inclined ones, the fact that the cleavage cuts the bedding on one side of each fold is very likely to be overlooked. As a result of the greater mashing thus developing cleavage or fissility the longer limbs of the folds are thinned more than the shorter limbs.

If for any cause cleavage be parallel to the bedding planes, as these are apt to be shearing planes in the zone of fracture, the predominant fissility would be likely to be parallel to the bedding. The other direction of fissility would be transverse to the bedding, and might have a wider spacing. The first might be called fissility and the second joints.

In another case, after a cross cleavage has developed and the rocks have passed into the zone of fracture, the stresses may result in the development of fissility along two sets of shearing planes, one of them being controlled in direction by the cleavage, the other by the bedding. The more regular parting, parallel to the cleavage, might be called fissility, and the less regular parting, parallel to the bedding, might be called either fissility or joints, depending upon its closeness. Whether the intersecting planes of fissility are at right angles to each other would depend upon the inclination of the cleavage and the bedding.

In regions of complex folding it is difficult to make accurate general statements of the relations of cleavage and fissility to bedding. However, as a result of the action of the various forces, a bed has a definite strike and dip, and the cleavage and fissility have definite relations to these. As there are rapid variations in strike and dip in regions of complex folding, it is to be expected that there will be variations in the directions and character of cleavage and fissility. Certain of the specific relations of bedding and secondary structures in regions of complex folding have already been considered (pp. 347–349).

RELATIONS OF CLEAVAGE AND FISSILITY TO THRUST FAULTS.

Between cleavage and fissility developed along the longer limbs of folds and thrust faults, which accord in dip with the beds on the longer limbs, there is only a difference in the magnitude and frequency of the movements.

When fissility or cleavage develops there are many slightly or infinitesimally separated movements of small degree. When a thrust fault develops there is a single major movement. It is believed that the relief is more likely to be by faulting at little depth, and at greater depth is more likely to be by the development of cleavage, and often, secondary to it, fissility, or more rarely by the development of fissility directly. The passage of cleavage by gradation into minute overthrust faults is beautifully illustrated a short distance northwest of Blowing Rock, N. C. Where fissility is not developed throughout the rock mass it may occur adjacent to thrust faults, due to the shearing adjacent to the thrust planes. Rock masses deformed by thrust faults and showing fissility adjacent to the faults will have zones of fissility which alternate with others in which this structure is absent. Where fissility varies in perfection of development in alternating zones, but is present throughout the rock mass, it implies that the relative movements were concentrated to a certain extent along definite zones, but that movement everywhere occurred. It is plain that *shearing developing cleavage and fault slips along planes of fissility accomplish the same mass deformation as do thrust faults*, only it is averaged throughout the rocks instead of being largely concentrated at certain planes.

Differential movements similar to those described in the above paragraph may occur along a lamellar structure in any kind of a rock, sedimentary or igneous.

By differential movements, such as are above described, enormous masses of material may move forward long distances The top of the mass, having the advantage of all the differential movements below, will travel the farthest (Figs. 5 and 6, p. 468). The base will move the least. From this mass at some later time

mountains may be carved. As each stratum grinds over the one below it the former presses against the latter with all the weight of the superincumbent material. Under such circumstances it is no wonder that a coarse-grained, massive granite may be transformed into an evenly laminated schist. In the zone of fracture the schist, developed in the zone of flow, may become fissile, and the slickensided, wavy folia may be thinner than paper. It is by folding combined with differential movement that the abnormal folds described on a previous page are produced.

The cleavage or fissility so frequently present upon the flanks of anticlinal core-rocks in great mountain ranges may be explained by similar movements. In the section on the analysis of folds it has been shown that much readjustment must occur upon the limbs of folds. The flanks of an anticlinal mountain core are such limbs, and hence the development of cleavage or fissility parallel to the central massif. In passing toward the center of the core we approach nearer the crown of the anticline, and penetrate to a greater depth ; hence less readjustment is necessary, and therefore the secondary structures are less prominent.

RELATIONS OF CLEAVAGE AND FISSILITY TO THICKNESS OF STRATA.

Without reference to the origin of secondary structures, or any evidence upon this point, bedding and secondary structures are often spoken of as corresponding. Even reputable textbooks make such statements. This confusion is most unfortunate for two reasons. (1) It often leads to great overestimates of the thickness of strata, the real thickness of the beds being supposed to be the apparent thickness as observed across the secondary structure, where, as shown by the foregoing analysis, the same bed may be repeated many times. (2) The mistake is likely to give erroneous ideas of structure. If the primary and secondary structures are thought to correspond, the whole breadth of a slate or schist may be regarded as a bed of enormous thickness, and this will lead to the preparation of sections in which the mass is represented as extending to a great depth, where it may be comparatively superficial. (Fig. 12.)

The assumption that bedding and secondary structures correspond is still less justifiable when no remaining evidence of bedding is found. If only cleavage or fissility be found and the relations of the beds with other beds are not such as to give the direction of stratification, no inference in reference to this point should be drawn.

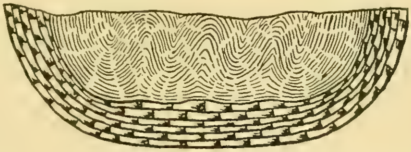

FIG. 12. — Closely plicated shale underlain by bed of limestone.

It is apparent that attempts to estimate the real thickness of cleaved or fissile beds must take into account two difficulties: (1) The same bed may be folded on itself many times, and these folds must be followed, or at least some estimate must be made of the thickness of the beds which would be present if the minute plications could be straightened. (2) In the complex folding of the beds there is readjustment, mashing and consequent lengthening of the layers upon the limbs, and they are, therefore, on the average, thinner than originally. So far as such thinning occurs, it compensates for the reduplication of the beds, but it is believed that this compensation is far short of full correction. To fully overcome these difficulties is often impossible, and estimates of the thickness of closely folded, cleaved, and fissile beds, even when all the difficulties are wholly understood and allowances made, are usually only approximate.

DEVELOPMENT OF CLEAVAGE BY OTHER CAUSES THAN THRUST.

Thus far I have considered cleavage developed in connection with and dependent upon orogenic movements. It is probable that this structure develops in other ways. It may be that deeply buried beds may become cleavable with the structure parallel to bedding, where superincumbent pressure, cementation, and metasomatic changes are the predominant forces.

Such deep-seated rocks, if below the level of no lateral stress, are in the zone of great vertical compressive stress and circumferential tension. They would, therefore, be shortened vertically. If under the stress of gravity movement goes far enough, this would develop a cleavage parallel to the surface. Such cleavage in sedimentary rocks would be parallel cleavage and would emphasize the bedded structure originally formed. Just below the level of no lateral stress it is probable that the circumferential dilation would be slight, but would increase with depth. Whatever its amount, it is a real cause so far as it goes.

It is not asserted that rocks in which cleavage may thus develop reach the surface by subsequent denudation, but perfectly crystalline schistose rocks in which the cleavage corresponds exactly with the bedding, and which are but gently folded, suggests that such may have been the conditions under which the structure formed, and if the estimates given for the depth of the level of no lateral stress, from two to eight miles,[1] are correct, it is certain that rocks which have been below this level in some regions have subsequently reached the surface by denudation. It is generally believed that the Laurentian and Adirondack areas are regions of profound erosion, and here are found excellent illustrations of gently folded cleavable schists, the structures of which apparently correspond with original bedding. The above explanations may be applicable to these regions. This method of the development of cleavage parallel to the surface of the earth below the level of no lateral stress is also applicable to igneous rocks.

Laccolitic or batholitic intrusives might promote this process by giving great pressure parallel to the bedding and by heating percolating waters, thus rendering them more active. In the Adirondacks the cleavage of the schists and the periphery of the batholite of gabbro have in some places a parallel arrangement, and the intrusion of the igneous rock has probably been one of the causes of the metamorphism and the parallel relations

[1] Origin of Mountain Ranges, by JOSEPH LE CONTE, JOUR. OF GEOL., Vol. I, 1893, pp. 566–568. JAMES D. DANA, Manual of Geology, 4th ed., 1895, pp. 384, 385.

obtaining between schistosity and bedding. Readjustment between the beds, as explained on a previous page, may also have assisted in the process.

In a third case, a great boss of intrusive igneous rock may cause the secondary structure to be everywhere parallel to it, without reference to the direction of previous structures. This case probably differs but little from that of direct thrust, but the direction of thrust gradually varies through 360° in circumscribing the mass, being at all times radial. The material pushed aside obeys at each point the law of normal plastic flow, just as in ordinary orographic movements. The new minerals develop with their shortest diameters in the direction of thrust. Old minerals are mashed into similar forms in parallel positions. The heat of the igneous rocks furnishes hot solutions which help to transform the old minerals. As the direction of the thrust varies gradually around the intrusive, the secondary structures follow, and therefore form a zone around the intrusive, the layers of which may be compared to those of an onion (see pp. 454–456).

The process may be complete, and old structures, such as bedding, previous cleavage, or previous fissility, may be wholly destroyed. In other cases traces of these structures may still be found. Where the earlier structures are wholly obliterated near the intrusive, they may appear gradually in passing away from it. Thus in the same rock mass several structures may occur. The mica-schists about the intrusive granite core of the Black Hills are an excellent illustration of this case.

MODIFICATIONS OF SECONDARY STRUCTURES.

The partings of fissility may be concentrated here and sparse there. In the cracks between the laminæ a new mineral or minerals may be deposited from water solutions, and the secondary zones of greatest fissility would then have a composition different from that of those which are less fissile. Moreover, the parted laminæ and the minute layers of infiltrated material may be of different composition. This would give a minute

alternation of layers of different characters. Such a major and minor alternation of different materials may simulate the appearance of bedding to a remarkable degree. If such structures are taken for bedding, mistakes in structural work will follow.

Where fissility is developed in an igneous rock, secondary impregnations may occur between the laminæ, just as above described. Thus there would be formed a rock with alternating layers of different mineral character, no part of which is sedimentary, and yet which closely simulates a sedimentary structure. If either the sedimentary or the igneous rock which has become fissile be intruded by igneous materials, these might follow the cracks in a minute way, and thus again produce a structure which is very similar to bedding.

In the above cases both the process of water impregnations and that of igneous injections tend to cement the rock. If the process be complete the crevices of the rock may be entirely healed. The once fissile rock will then have lost its fissility. It may, however, have the property of cleavage parallel to the banding. Such a cleavable rock may give no evidence that it was once fissile. From the foregoing I conclude that *banded rocks may owe their structure to fissility and secondary impregnations or injections, or both, and the bands may or may not accord with an original structure.*

After a first secondary structure has developed, later movements may produce a new cleavage or fissility, which cuts this earlier structure at right or oblique angles, or the new force may be so intense as to produce a structure which wholly destroys the earlier structure. Usually, in order that a new structure may be produced, it is necessary that the new force shall vary considerably in direction from the first, so that it cannot be decomposed into two components, one parallel to the old structure and one at right angles to it. To this fact is doubtless due the comparative frequency of cleavage and fissility in several directions in the same rock mass; but while the secondary structure is ordinarily in a single direction, an exposure or even a hand

specimen may show the original bedded structure and secondary structures in two or more different directions. In fact, as has been shown, a single simple orogenic movement may produce both cross and parallel secondary structures, and the cross fissility may be in two directions.

While it is rare to find more than two or three structures in a rock, theoretically there is no limit to the numbers which might be produced; but practically, as has been seen, new movements usually emphasize old structures, or else produce new structures, which tend to obliterate the old structures. *However, in a thoroughly crystalline rock, if there be two or three structures, it is not safe to assume that the oldest and most intensely plicated one is bedding.* This has been done frequently in the case of the crystalline schists and gneisses by those who would not regard cleavage or foliation, if but a single structure existed, as evidence of bedding. The older the structure the greater is the probability that it is really bedding, but the fact that it is the earliest structure which now exists in the rock cannot be regarded as conclusive, for it may have been produced by an early orogenic movement which simultaneously obliterated bedding.

After a secondary structure has developed in a formation it may be folded into anticlines and synclines. In order to be thus folded it is usually necessary that the secondary structures be not steeply inclined. As indicated on a previous page, where such a structure develops in a horizontal position it may correspond with bedding, but also it had been seen that cleavage or fissility may form with slightly inclined planes of movement which cut diagonally across the bedding. Such a cleavage or fissility may be emphasized by secondary impregnations and injections, in which case it simulates bedding to a remarkable degree. In either of the above cases a careless observer would be almost certain to regard the structures as bedding.

The number and severity of orogenic movements may in many places have been so great along old ranges that it is not strange that it is impossible to differentiate or separate the various formations upon a structural basis. The beds have

been kneaded again and again by the orogenic forces; cleavage, fissility, and band banding may have developed in different directions; earlier structures may have been destroyed by later transformations; until it is no longer possible to determine the position of original bedding.

APPLICATION TO CERTAIN REGIONS.

In many mountainous regions in which there has been profound erosion, illustrations of nearly all of the foregoing principles may be found. Attention may be directed to one or two of the more important.

It has already been pointed out (pp. 337–338) that in the Appalachian and New England crystalline areas the main direction of active stress was probably from the southeast toward the northwest. At any rate, the couple composed of force and resistance was such as to make the higher strata move toward northwest as compared with the lower strata, or to make the lower strata move to the southeast as compared with the upper strata. As a consequence of this, the folds of that area have axial planes which have a very general tendency to dip to the southeast. If the force be supposed to have been directed toward the northwest, and to have been equal for different depths throughout the thickness of the rocks now exposed at the surface, the cleavage which developed in the normal planes would dip to the southeast. This would have been due to two causes: First, the direction of normal pressure, compounded of thrust and of gravity, would have been northwest and downward, which would, therefore, have given a southeasterly dip to the cleavage. Also, because of increasing resistance and probably lessening thrust with increasing depth, the force would have caused the higher strata to have moved differentially over the lower ones. There would, therefore, have been a shearing motion, the higher strata moving upward and northwestward as compared with the lower. As a result of this shearing and of shortening, the old and new mineral particles would lie with their longer diameters in southeasterly-dipping planes and give a cleavage in that direc-

tion. The conjunction of these two forces would have given a flatter dip than would follow from either one of them alone.

While the above statement is true on the average, the case is complicated because of the differential movements in individual folds. The cleavage for a given section is in a single direction to the southeast only when the folds have a decided monoclinal attitude, and this is especially marked where the folds are all overturned. Even here, however, the cleavage tends to be flatter upon the limbs in normal positions than on the overturned limbs. In the areas in which the folds approach a symmetrical character, cleavage with northwest dips is found on the northwest limbs of the folds. The explanation of these phenomena is given on pages 461–475.

While there is a general tendency in this region for a southeasterly-dipping cleavage, there are great variations in the steepness of the dip in different beds in the same locality, and variations in the average steepness in different localities. The variation in steepness in the same area is explained by the fact that the differential movement between the strata was largely concentrated in the weaker beds, so that the cleavage in them is flatter than in the more resistant beds. The general variation in the dip of cleavage in passing from area to area may be explained by a difference in the character of the rocks, by a difference in the intensity of the forces at varying depths, or by a difference in the depth of burying. The particular average inclination for a given area depends upon a combination of all these variables.

With given forces, if the rocks are more resistant in one area than in another, there is less shearing motion, and therefore steeper cleavage in the former than in the latter. Other things being equal, if the forces are more intense near the surface than at a greater depth, the shearing motion is greater at higher horizons, and hence the cleavage is flatter in passing toward the surface. A given force would produce less and less shearing motion with increasing depth, because of the increased friction, and hence the cleavage may be flatter in passing toward the surface, just as in the foregoing case.

For any given area, after cleavage developed, as denudation progressed the zone of flowage passed upward into the zone of fracture. It is clear that the cleavage planes already developed were then probably shearing planes, and this was true even if the horizontal thrust was the same and in the same direction in the zone of fracture that it was in the zone of flowage, for the direction of greatest normal pressure is composed of thrust and gravity, and therefore at a great depth is steeply inclined to the horizon, whereas in the zone of fracture, gravity being less important, the direction of greatest normal pressure is less steeply inclined, and therefore normal planes in the zone of cleavage become shearing planes in the zone of fracture. In the development of fissility along the cleavage planes there were slight differential movements between the laminæ, and hence was formed the very extensive fault-slip cleavage so well known in the Appalachians. It is believed that the more regular and widespread fissility is thus secondary to cleavage, but it is recognized that fissility or joints formed in other directions, and that in the outer zone, which was never in the zone of flowage, original fissility or jointing only was developed.

As pointed out by Willis, in the western area of little altered rocks in the southern Appalachians the deformation was mainly by faulting; in the corresponding area in the northern Appalachians the deformation was mainly by folding. At intermediate areas the deformation was by faulting and folding. Parallel to the fault-planes fissility developed to some extent in the area of fracture, and dipping in the same direction as the monoclinal folds cleavage developed in the area of folding. In an intermediate area the deformation was by major faulting, by minor fault-slips along fissility, by the pure shortening and shearing motion producing cleavage, and by monoclinal folds, all combined. The interactions of these are more fully described in other places (see pp. 595–598, 620–622).

Returning to the crystalline area, in the cracks and crevices between the fissile laminæ mineral impregnation from water solution occurred at many places, and thus gave the rocks a

parallel banding, as described by Hobbs in the Searls quarry. In other districts parallel injections of igneous rocks occurred, and here the metamorphosed schists are wedded together along the fissile planes by igneous material. Such are the conditions in southeastern New York, and especially on northern Manhattan Island in the vicinity of New Rochelle.

As shown in other places (pp. 600–603), there may be all gradations between aqueous impregnations, through aqueo-igneous deposits, to true igneous injections. Usually the original rock differs in chemical and mineral composition from the impregnations or injections. The process gives a distinctly banded structure, which has often been mistaken for metamorphosed original sedimentary layers. Also the chemical composition may be so changed, if the amount of secondary material is large, as to make it impossible to tell from its chemical analysis whether the original rock is aqueous or igneous.

If the parallel mineral impregnation, or the parallel igneous injection, or the two together, had been general throughout the Appalachian semicrystalline and crystalline areas, we should have a vast series of crystalline schists with parallel banding, the bands generally dipping to the southeast, and these layers might be mistaken for beds, and thus lead to estimates of enormous thickness for the series, when in reality the original sedimentary beds were of no unusual thickness. This error has not been made for much of the Appalachian region because in most areas the metamorphism has not been so extreme but that the cleavage is detected intersecting the bedding at the sharp turns of the layers on the crests of anticlines and in the troughs of synclines. Had the metamorphism gone as far throughout the region as it has in certain places, the bedding could not be discovered, and there would be now no means of tracing out the different steps of the process of modification. But in the Appalachian and New England regions the steps of the process of the development of cleavage and fissility, the stages of the parallel impregnation and injection, and all degrees of metamorphism may be observed, so that in some of the regions of most

extreme change the genesis of the rocks and their structures are determined with reasonable certainty.

In the eastern region the areas in which the sedimentary rocks have gone through the process above described are more extensive than those of igneous rocks, but all steps of the process have also affected extensive areas of igneous rocks. Examples of the latter are the pre-Cambrian granitoid gneiss of the Green Mountains, and, more extensive than this, the great areas of ancient plutonic and volcanic rocks of the Blue Ridge and Piedmont Plateau.

It is believed that the regularly banded and laminated Laurentian gneisses which have an isoclinal dip over great areas in Canada, along the Madison Canyon in southwestern Montana, and in other regions, may be explained by the same processes completely carried out as applicable to the Appalachians. It is not asserted whether the original rocks in these regions were igneous or aqueous. The general drift of opinion in recent years is in favor of the former origin.

RELATIONS OF CLEAVAGE AND FISSILITY TO STRATIGRAPHY.

Cleavage or fissility may be developed in one set of beds and not in another set of beds in the same set of formations. Secondary structures develop readily in a shale, less readily in a fine grit, still less readily in a limestone, and perhaps with the least readiness in a quartzose sandstone, quartzite, or conglomerate. As a consequence of this, a shale between beds of limestone may take on a thoroughly cleaved or fissile character, the cleavage stopping abruptly at the beds of the limestone. The same is true of layers of shale between beds of grit, or sandstone, or quartzite, or conglomerate. In general, *in the strata constituting a formation, cleavage may develop in the less rigid beds and be absent or imperfect in the more rigid beds.* In such cases it has sometimes been assumed that the lower bed was deposited and cleavage or fissility developed in it before the superior bed was formed, the fact that a secondary structure was not so ready to develop in the upper bed being ignored.

In determining unconformities the use of cleavage and fissility follows the same principles as given on pages 351–353 in reference to folding. To safely infer that there is a structural break between series it is necessary to show that cleavage and fissility would be as likely to develop in the superior formations as in the inferior ones. It is further necessary that the two series be in actual superposition, not in adjacent lateral positions.

It has been seen that in proportion as cleavage and fissility develop, the original structures of the rock are obliterated. Where there is apparently complete destruction of the bedding for parts of folds, at areas of less movement, as, for instance, the crests of anticlines and the troughs of synclines, the beds may still be recognized, and thus the relations between the primary and secondary structures be determined.

JOINTS.

ORIGIN OF JOINTS.

Various causes have been assigned for joints, of which the more important are tension, torsion, earthquake shocks, and shearing. It is believed that joints may be classified into *tension joints* and *compression joints*. The first are ordinarily in the normal planes, the second are in the shearing planes.

Tension joints.—Tension is often due to the contraction caused by cooling or by desiccation. It is well known that the peculiar columnar jointing of igneous rocks is due to the contraction and consequent tension caused by cooling, and the mud cracks of sedimentary rocks are due to the contraction and consequent tension caused by desiccation. However, it is probable that neither cooling nor desiccation is important in the production of systematic sets of joints in the sedimentary rocks.

It has already been seen that when rocks are simply folded and not too deeply buried the convex halves of the anticlines and synclines are subjected to simple tension (pp. 205–208, Fig. 1). If the tension goes beyond the limit of elasticity, radial cracks will be formed which strike parallel with the rocks.

Joints of this class are at right angles to the tensile force. This class of joints is beautifully illustrated in the sharp folds of the graywackes of the Hiwassee river, in the Ocoee series. If the folded rock has planes of weakness of any kind, due either to a primary or secondary structure, the fracture due to the tensile stress may be controlled by these, and thus deviate from the normal planes.[1]

Joints produced by tensile stress may have smooth or rough surfaces, depending upon the character and strength of the rock. If it is a weakly cemented sandstone, the fracture, as pointed out by Becker, is around the grains. If, however, it is a strong, tolerably homogeneous graywacke, quartzite, or limestone, or similar rock, the fractures may be clear-cut and sharp. After joints due to tensile stress have formed, subsequent movements may press the surfaces together, or may fault the strata in a minor or major way, and thus produce slickensided surfaces.

It has been seen in the discussion of folds that, instead of being simple, and, therefore, in a horizontal attitude, they usually have a pitch; or, in other words, the rocks are folded in a complex manner. In such regions there may be tensile stresses in two directions at right angles to each other, thus producing two intersecting sets of joints. One of these sets, that roughly parallel to the more conspicuous folds, would be called strike joints, while the other set of joints, parallel to the transverse folding, would be called dip joints. Both sets would intersect the bedding nearly at right angles. The fact that two sets of joints in these positions so frequently accord in direction with the strike and dip is strong evidence that many joints are produced by the tensile stress of folding on the stretched half of

[1] BECKER states that "Tension will not produce joints or cleavages. The theory of the distribution of tension cracks is the explanation of columnar structure" (this JOURNAL, Vol. IV, footnote, p. 444). Where equal contraction occurs in all directions as the result of cooling or desiccation, this is well known to produce columnar forms, but where there is tension in only a single direction, this may produce one set of approximately parallel joints. Tension at a later time in a direction at a large angle to this may produce another set of joints. Or, finally, unequal tension at the same time in two directions nearly at right angles to each other may produce two regular sets of intersecting joints.

the mass folded. If the folds are nearly horizontal—that is, if the force was mainly in a single direction—the strike joints may be strongly developed and few dip joints produced. If, on the other hand, the folds are important in both directions, the strike and dip joints will both be important.

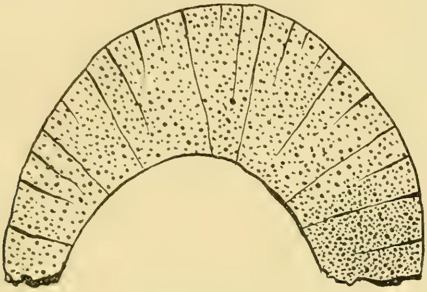

FIG. 13.—Radial cracks due to tension in sharply flexed stratum.

Daubrée has shown that if a brittle plate fractures when it is subjected to torsion beyond the limit of elasticity, a double set of parallel fractures nearly at right angles to each other are produced.[1] The forces which produce complex folding deform the strata, where not too deeply buried, in two rectangular directions by tensile stress; or, in other words, they are subject to torsion. It therefore appears that Daubrée's explanation of joints by torsion is but another statement of the production of joints by complex folding normal to the two principal directions of tensile stress.

A question for investigation is the extent of the area over which joints and faults run in rectangular directions. In the case of a large and strongly pitching fold, the force of torsion may produce rupture in different directions upon different parts of the folds. Upon the flank of the pitching fold, at a proper point, strike joints and dip joints may be formed, striking halfway between the ordinary strike joints and faults, and dip joints and faults at the crests and troughs, and between the two there would be all gradations.

[1] Géologie expérimentale, par A. DAUBRÉE, pp. 306–314, Paris, 1879.

Crosby has recently suggested[1] that when torsion has nearly, but not quite, reached the limit of elasticity in rocks, an earthquake shock may act as the trigger which sets the process in motion, and he thus combines this cause with torsion in explaining joints. Crosby also emphasized the fact that a plate when subjected to torsion does not crack along a single plane of fracture, the weakest plane, but that many parallel fractures are produced. He applies this fact to rock beds, and suggests that the fracture must first occur at some one plane, that of the greatest stress or least strength in the distorted belt. The shock of the fracture, added to the force of torsion, goes beyond the ultimate strength of the beds at the next weakest plane, thus fracturing them and producing another joint, and so on, until the complicated fracturing actually obtained in the glass plate is paralleled by the rocks. He thus makes the rupture of the first joint itself serve the purpose of a secondary shock, and this rupture a third shock, and so on, producing a set of joints in rapid succession over an extended area. Finally a place is reached where the rock has not been sufficiently distorted for the shock of the last fracture to carry the stress beyond the breaking strength. This theory is as applicable to simple tension as to torsion. In the above it appears that Crosby has overlooked the fact that he has not explained the first earthquake shock. The statement might be amended as follows: The first fracture occurs because the steadily acting orogenic forces finally go beyond the ultimate strength of the deformed beds. When rupture takes place, this gives the first shock. This initial shock carries the stress beyond the ultimate strength of the next weakest planes, and so on.

Compression joints.— Daubrée[2] and Becker[3] show that joints may be produced by compression. In this case there will be jointing in two planes when the rocks are simply folded, and,

[1] The origin of parallel and intersecting joints, by W. O. CROSBY, Am. Geol., Vol. XII, 1893, pp. 368–375.

[2] Géologie expérimentale, par A. DAUBRÉE, pp. 315–322, Paris, 1879.

[3] GEORGE F. BECKER: Finite homogeneous strain, flow, and rupture of rocks. Bull. Geol. Soc. Am., Vol. IV, pp. 41–75, 1893. The torsional theory of joints. Trans. Am. Inst. Min. Engineers, ol. XXIV, pp. 130–138, 1894.

according to Becker, there may be jointing in three or four planes when they are complexly folded, one of these being normal to tensile stress and the others in shearing planes. However, where there are more than two sets of joints at right angles to each other, it is probable that in many cases these have been caused by successive orogenic movements, the second being in a different direction from the first. Becker has explained that minor faulting is a common phenomenon of compression joints.

When the folding is simple, both sets of joints developing in the shearing planes, although dipping in different directions, would accord in their outcrop with strike, and might therefore be regarded as strike joints. When the folding is complex it may be that different sets of shearing planes would correspond to strike joints and dip joints, but upon this point further observation is needed.

In the Knox dolomite of east Tennessee the formation of joints along both tensile and shearing planes is beautifully illustrated at numerous localities. Commonly the joints produced by tensile forces are nearly perpendicular to the bedding. Two sets of joints, equally inclined to the bedding and making obtuse angles with each other, are clearly in the shearing planes.

The attitudes of joints produced by shearing and their relations to bedding would be identical with fissility, as described on pages 593–597. Whether the structure be called fissility or joints would depend upon their number. If numerous and close together the structure would be called fissility; if fewer and farther apart, jointing. The same compression might produce fissility along one set of shearing planes, and joints along another. If the above be true, it is clear that there are all gradations between joints and fissility. It has been suggested that the term "fissility" might perhaps be wisely restricted to the cases where the structure is secondary to a previous one, such as cleavage or bedding, and that the term "joint" should be used to cover fractures along independent shearing planes.

In thus explaining many joints as the result of the same forces which produce folds, it is not meant to imply that there

are not joints of other origins, but merely that the master joints, which run in different directions approximately parallel to the strike and dip, may be thus explained, and these are the joints which are the most useful in determining the structural relations of different series.

ZONE AFFECTED BY JOINTS.

Joints, implying as they do openings in the rocks, are necessarily confined to the outer zone of fracture and the middle zone of fracture and flowage. In the first zone they are of more importance and probably more regular than in the second. In the deeper zone of rock-welding no joints can develop. In rocks once buried to this depth, which subsequently reached the surface by erosion, joints may be formed; for in approaching the surface they passed from the zone of flowage, through the zone of fracture and flowage, into the zone of fracture.

RELATIONS OF JOINTS TO STRATIGRAPHY.

If there is a greater number of sets of joints in an inferior formation or formations than in a superior formation or formations, the two divisions being of such lithological character as to be equally likely to take on jointing, this argues that there may be discordance between the two sets, for it is probable that the lower set of formations, which has the more complicated jointing, was subjected to orogenic movements which produced a part of these fractures, before the upper series was deposited. Comstock has applied this as the determining criterion in separating three supposed series of rocks in the Llano district of Texas. The lower series of formations is said to have three sets of pronounced joints running in definite directions, while the middle series has only two sets of joints running in definite directions, these two being common with two of the three in the lower series, and the upper series has a single set of joints running in a definite direction, this system being common to both the inferior series. Comstock's inference is that the system of joints in the lowest series not found in the upper two series was produced

before the upper two series were deposited, and that the two sets of joints found in the lower series, one of them also affecting the middle series, and both absent in the upper series, were present before the latter series was deposited. That is, the lower series was subjected to three orogenic movements, the middle series to two, and the upper series to one. Considering that two or more sets of joints may be developed by a single orogenic movement, it would seem that such a conclusion should be supported by other criteria.

FAULTS.

ORIGIN OF FAULTS.

Faults differ from other rock fractures, in that there is importtant dislocation along the fractures and often also they are far more extensive. Like joints, faults may be classified into *tension faults* and *compression faults*, the first forming in the normal planes and the second in the shearing planes. Faults are, however, usually defined as normal and reverse. A *normal fault* is one in which the overhanging side descends in reference to the other, while in the reverse fault the overhanging side ascends in reference to the other. Another term applied to reverse faults is *thrust faults*, implying that tangential thurst is the controlling factor. As equivalent to normal fault may be placed the *gravity fault*, implying that gravity is the predominant force.

In the case of the normal fault the overhanging side has a smaller base than the other. Consequently by force of gravity it descends, as compared with the other side. In all cases both of normal and reverse faults, gravity is a never-ceasing force. At first explained by Le Conte,[1] the principle of the inclined plane thus applies to these two forces, the hade of the fault giving the inclination of the plane. Where the hade is greater than 45° if the forces of gravity and tangential thrust are equal the fault is normal, because gravity controls the movement (Fig. 14). If, on the other hand, the hade is less than 45°, tangential thrust is

[1] On the origin of normal faults, and of the structure of the Basin region. JOSEPH LE CONTE. Am. Jour. Sci. (3), Vol. XXXVIII, 1889, pp. 257–263.

the predominant force, and the fault is a reverse one (Fig. 15). As the hade becomes steep, gravity has greater and greater relative power, and if the hade is very steep, gravity may be able to overcome the tangential thrust, even if the latter is several times as great as the former. So, also, if the hade is flat, tangential thrust even much weaker than gravity may overcome it and pro-

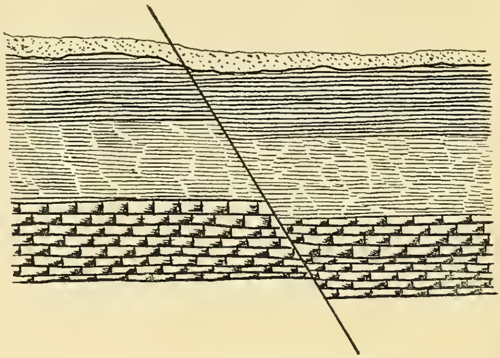

FIG. 14.—Normal or gravity fault.

duce a reverse fault. This is one reason why, as a rule, normal or gravity faults have steep hades, while reverse or tangential faults have flat hades.

There is, however, another reason. Since tension faults form in the normal planes, they are usually steeply inclined or nearly vertical. But the very idea of tension faults implies that there is no thrust. Hence, gravity has its full effect, and the overhanging side goes down with reference to the other side. It does not follow, therefore, that all gravity faults are tension faults, although this may be the case. Compression faults form in the shearing planes, and they are therefore likely to be much inclined to the vertical. In order that rupture shall occur the thrust must be great, and hence compression faults are usually, and perhaps always, thrust faults.

Perhaps it would be well to classify faults as gravity faults and thrust faults rather than normal and reverse faults, and thus give them names which refer them to the predominant causes. For the present this classification is preferable to the classifica-

tion into tension faults and compression faults; for it is possible, though hardly probable, that an inclined fracture may result from compression, and after a time thrust lessen in amount, so that gravity controls the final differential movement.

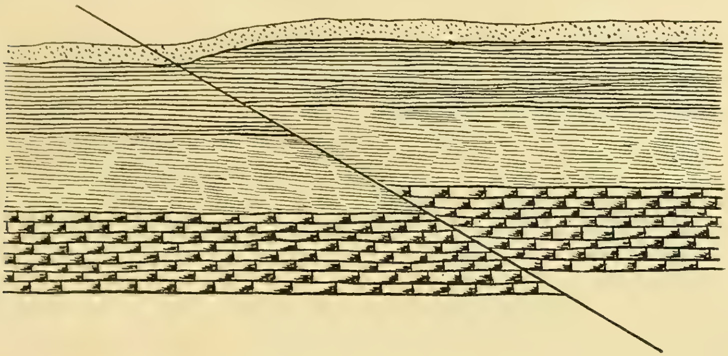

FIG. 15.—Reverse or thrust fault.

RELATIONS OF FAULTS TO EXPANSION AND CONTRACTION.

Gravity faults result in the dilation of the part of the crust affected by them (Fig. 14). Thrust faults result in the contraction of the part of the crust affected by them (Fig. 15). In a region in which many parallel faults occur, all of the same character, the dilation, or contraction may be a considerable percentage of the breadth of the area disturbed. Since the amount of dilation or contraction with a given vertical movement increases as the hades become flat, and since thrust faults have flatter hades on the average than gravity faults, the shortening of the crust in a region of thrust faults is usually greater than the elongation in another region in which gravity faults are about equally abundant and in which the vertical displacements are the same.

RELATIONS OF FAULTS TO STRIKE AND DIP.

While there is great variability in the direction of faults, due to exceptional causes, faults are more parallel to the strikes and to the dips, other things being equal, than in other directions, so that faults are sometimes spoken of as strike faults and dip faults.

Since a fault may be no more than a displaced joint, this relation is easily explained in the same manner as in the case of joints. (See pp. 610–612).

RELATIONS OF FOLDS TO THRUST FAULTS.

It has been long recognized that thrust faults are often related to overfolds. If the strata are in the zone of combined fracture and flowage, the overfolds may be broken along the reversed limbs and the arch limbs be thrust over the trough limbs. In a region of overfolds and thrust faults, if it could be determined whether the differential movements are such as to carry the material moved toward the surface or away from the surface, it could be decided whether such folds and faults should be called overthrusts or underthrusts.[1] But the differential movements, the forms of inclined and overturned folds, and the character of the thrusts are identical, whether a given bed above be considered as moving forward and upward as compared with the layer below, or be considered as moving forward and downward as compared with the layer above. In Fig. 16, if the force be considered as applied at A, it would be called an overthrust fault; if the force be considered as applied at B, it would be called an underthrust fault; and yet the phenomena are identical. The movements must be such that the material goes in the direction of relief, and it is probable that this is more often toward the surface of the earth (see pp. 338, 339) rather than deeper within the earth. It is probable that in certain cases thrust has been transmitted by a strong formation or series and pushed under other strata. This is particularly likely to occur where the lower strata are weaker or where the material in advance of the active strata transmitting the force has been already raised into folds, and thus partly escapes the pressure. (See pp. 316–319, and Fig. 6.)

As explained by Willis, in regions which are but lightly loaded the forces producing thrust faults may result in clean-cut

[1] The term underthrust is taken from PROFESSOR E. A. SMITH. Am. Jour. Sci., 3d series, Vol. XLV, 1893, pp. 305, 306; see also this JOURNAL, Vol. IV, p. 339.

fractures, with scarcely any bowing of the layers of the rocks along the shear planes (see Figs. 4 and 6 on p. 468, and pp. 596–598). In passing to the greater depths the load is greater, and the layers, instead of all having the full movements of the clean-cut thrust faults, adjacent to the fault planes may be found to be in sharp overfolds in opposite directions upon opposite sides

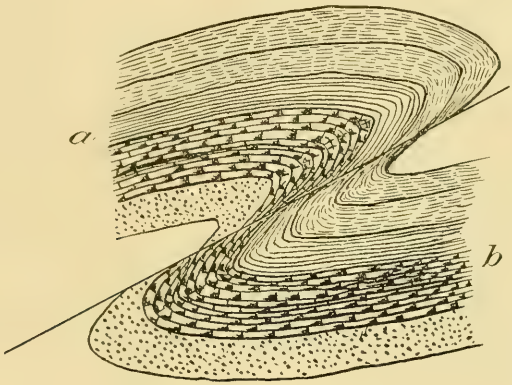

FIG. 16.—Fold passing into fault.

of the faults (Fig. 16). Where the load is still greater these folds are of increased importance. Under still greater load the rocks may be first bent into an overfold, with little faulting, and finally at a greater depth the deformation may occur altogether by overfolding. It is therefore clear that in the same mountain mass there may be all gradations between clean-cut thrust faults and overfolds without faults. The transition may be longitudinal, as in the case of the Appalachians, where thrust faults which occur in the extreme southeast are gradually replaced by overfolds to the northwest. Also the transition may be transverse. In the latter case, if erosion cuts the strata to different depths after such a region was deformed, the overfolds may be found in the central parts of the mountain mass, the transition phases upon the immediate areas, and the thrust faults without overfolds upon the outer flanks of the mountains.

Rocks at a certain depth, and therefore under a definite load,

may be deformed first by folding and afterwards by faulting. Suppose a rock is deeply buried, but not so deeply as to cause the superincumbent load to equal its ultimate strength. Suppose the differential stress for a given stratum under these conditions to surpass the elastic limit, but not to reach the ultimate strength of the bed. It will then be deformed by folding, but during the process shearing occurs on the limbs, and as a result the bed is thinned, and finally the stress may surpass the ultimate strength of the rock, which will then be fractured and perhaps faulted. The same result may be reached if before a stratum or formation is thinned the differential stress increases so as to go beyond the ultimate strength of the rock. It follows from this that deformation by folding followed by faulting is normal for a considerable zone, for when the mountain-making forces for a given region first begin their work it is to be supposed that the differential stress is moderate. As the stress increases in amount so as to exceed the elastic limit the layers would begin to be folded, and fracture would occur as soon as the differential stress reached the ultimate strength of a given layer, provided the rock was not in the deep-seated zone of flowage.

It has been seen (p. 597) that accompanying thrust-faulting fissility may develop parallel to the faults, and accompanying overfolding cleavage may develop which dips in the same direction as the axial planes of the folds. In an area intermediate between the zone of fracture and the zone of flowage, this being at successive times under the conditions of flowage and of fracture, there may be overfolding and cleavage combined with thrust faults and fissility. In passing from a faulted to a folded area, as has been noted, first there may be fissility along the thrust faults, then the strata may be slightly overfolded and tucked under along the faults, this undertucking becoming more and more prominent and fissility at the same time being replaced by cleavage, and finally we may have overfolds with cleavage, with or without faulting. Each of the different phases of the steps of change may occur on a large or small scale. In

some places in an intermediate area a dozen little overfolds with fault slips may be seen upon a single hand specimen. Hence I conclude that *the average deformation of a region may be the same whether it be by a few great faults with little or no fissility, by more frequent lesser faults with or without fissility, by faults and overfolds with or without both cleavage and fissility, or by folding with or without faults and cleavage;* also that *there is every gradation between faulting and fissility, and probably every gradation between faulting and cleavage.*

ZONE AFFECTED BY FAULTS.

A fault may vary in magnitude from a fraction of an inch to many thousands of feet. A fault, like a joint, is limited in horizontal as well as vertical extent. It cannot be assumed to extend very far beyond where observed. A fault of an inch may die out within a few inches, both laterally and vertically; a fault of a hundred feet within a few hundred feet; a fault of five thousand feet within a few miles. In following a fault longitudinally the throw may be found to become less and less until it is zero, just as a bunch of paper may be torn for a part of its length and the different parts of the torn ends be differently displaced. But while faults may thus die out within short distances, they may have remarkable persistence, both in direction and in length. This does not necessarily imply that they have great persistence in depth, for just as a fold has a tendency to die out, as explained (pp. 210, 211), a fault may also die out below, and sometimes also above. In the latter case the fault usually occurs in a stratum or a formation which is brittle as compared with the overlying rocks. Because of the more plastic character of the higher strata the deformation there occurs by folding. *Probably most faults at sufficient depth pass into flexures, and deeper down these flexures may die out.* As already explained, when a bed is deformed under little weight the strain necessarily causes fracture, and the readjustment is largely by faulting along the fractures. When all the conditions are the same, except that there is such load that as a whole the rocks are in

the zone of flowage, the necessary deformation is accomplished by folding. In regions of close folds it is probable that before the superincumbent beds were removed by erosion many of the latter were faulted instead of folded, for they were in the zone of fracture and flowage, and in the zone of fracture rather than the zone of flowage.

Possibly the depth at which important faults disappear is in many cases not more than 5000 meters, although the discussion of the depth of earthquake shocks due to faults leads to the conclusion that some faults extend to the depth of a number of miles.

If there are inclined planes of weakness in the deep-seated zone of flowage, the deformation may largely occur by faulting along these planes.[1] Such inclined planes of weakness may be in sedimentary rocks or in igneous rocks. Since masses of intrusive rocks, either in the form of dikes or of bosses, usually have vertical or steeply inclined exteriors, faulting is particularly likely to occur at the contacts of igneous rocks with one another, or at the contacts of igneous with sedimentary rocks. It has already been explained that such deep-seated faults would differ in no way from the differential movements resulting in cleavage or fissility, except that the movements are mainly confined to narrow zones. This results in great displacement at the fault zones and little displacement in the areas between the faults. In such supposed deep-seated faulting it is to be remembered that the displacement takes place without crevice or joint. At any given movement the rock is to be regarded as welded together. The different parts simply shear over one another along the plane of greatest weakness.

RELATIONS OF FAULTS TO STRATIGRAPHY.

Faults may be used to discriminate between series in precisely the same way as joints, and the criterion has far greater weight. If an inferior set of formations has a more

[1] The Mechanics of Appalachian Structure, by BAILEY WILLIS. Thirteenth Ann Rept., U. S. Geol. Surv., pp. 217–274, 1893. Especially Pls. XCV and XCVI.

complicated faulting than an upper series which lithologically is equally likely to be faulted, this is strong evidence that the lower set of formations was faulted before the upper set of formations was deposited. Faults are frequently not easy to demonstrate or to trace out. Hence this criterion for discriminating between series is not so valuable upon the whole as are the more conspicuous and readily discovered phenomena of folds, cleavage, fissility, and joints, but if the conditions are favorable for tracing out the faults of a region, the information thus furnished may give positive evidence as to structural breaks between series.

GENERAL.

In the foregoing pages folds, cleavage, fissility, joints, and faults are regarded as the conjoint products of thrust and gravity. Similar forces acting upon heterogeneous rocks under various conditions produce diverse phenomena. Thus several classes of phenomena which are often treated as independent and unconnected are genetically connected. A fault may accord in inclination with any of these structures. Between faults and joints, fissility, or cleavage there are all gradations. When there is a marked displacement along a break it is called a fault. Whether a given minor displacement is thus named often depends upon the point of view. Wherever there is fissility there is slipping or faulting, using this term in its exact sense. Usually minor displacements are not called faults unless they occur across the beds or other structures. A displacement across a prior structure of such magnitude as to be called a fault might be ignored if it occurred along the structure. Folding and cleavage belong normally to the zone of flowing; fissility, joints, and faults belong normally in the zone of fracture. In the zone of combined flowage and fracture all the structures occur together in a complex manner, the particular combination of phenomena depending upon the relative thickness, strength, and brittleness of the rock beds concerned.

AUTOCLASTIC ROCKS.

ORIGIN OF AUTOCLASTIC ROCKS.

When rocks are folded by strong orogenic forces, and they are not so heavily loaded as to render them plastic, they are frequently broken into fragments, and "*autoclastic*"[1] rocks are produced. The autoclastic rocks which readily show their origin may be called *dynamic breccias*, and those which resemble ordinary conglomerates may be called *pseudo-conglomerates*. Brittle rocks are the most likely to become autoclastic; hence it is that cherts, quartzites, cherty limestones, graywackes, and rather siliceous slates are some of the kinds which most frequently present the phenomena described. The movements of the broken fragments over one another in many cases so thoroughly round them that they have the appearance of being waterworn, and the matrix between the larger fragments may consist almost wholly of well-rounded fragments of a similar character. For instance, in a semi-indurated quartzite the larger complex fragments may be well rounded by their mutual friction while the matrix may consist of the simple original waterworn grains which are rent apart. In another case the original rock may have consisted of beds of mud interlaminated with thin beds of grit. By consolidation and cementation these beds may have been transformed to alternating shale and graywacke. The shale is plastic under slight load; under the same load the graywacke is brittle. When such a set of beds is deformed the shale yields largely by flow and the graywacke by fracture. The beds of graywacke are broken into fragments of varying sizes, which are ground over one another, and thus are rounded. At the same time the shale flows and fills the spaces between the fragments. Also slaty cleavage may be developed. As a result, a pseudo-slate-conglomerate is produced, having a slate matrix and pebbles of graywacke, which, so far as its own characters are concerned, could not be discriminated by anyone

[1] Structural geology of Steep Rock Lake, Ontario, H. L. Smyth, Am. Jour. Sci., 3d ser., Vol. XLII, p. 331.

from a true conglomerate. Fortunately, in most cases it is possible to find transition phases between such a rock and one in which the process has not gone so far, and thus one is enabled to determine that the rock is autoclastic.

ZONE OF AUTOCLASTIC ROCKS.

The zone in which autoclastic rocks may be produced is confined to the outer 10,000 meters of the earth's crust, and the formation of widespread autoclastic rock is probably limited to the outer 5000 meters. At a depth greater than the larger number the pressure in all directions exceeds the crushing strength of any rock, and therefore if it were possible for crevices to form such as are necessary to produce brecciation they would be almost immediately closed by flowage. Consequently, at great depths it is to be supposed that no crevices form in the rocks as the result of dynamic movements, and therefore that no breccias are produced.

From the foregoing it follows that autoclastic rocks may develop whether the formations concerned are homogeneous or heterogeneous. Also that they may develop whether the beds are all within the zone of fracture for them or whether they are in the zone of fracture for a part of them, and in the zone of flowage for the other part. In the first case dynamic breccias are likely to form. In the second case only the stronger rocks are broken, the fragments being buried in the members which flowed, and pseudo-conglomerates are frequently formed.

RELATIONS OF AUTOCLASTIC ROCKS TO BASAL CONGLOMERATES.

Since it is possible that pseudo-conglomerates may be mistaken for true basal conglomerates, the criteria which discriminate the two are of great importance.

(1) An autoclastic rock must derive its material mainly from the adjacent formations. If, for instance, it is produced from interstratified layers of limestone and quartzite, it will contain only limestone and quartzite detritus, and the fragments will be mainly from the more brittle formation. Further, an

autoclastic rock may have a part of its material from the superior formation as well as from the inferior. However, in some cases the brecciated layer may itself have been conglomeratic, although not a basal conglomerate, and thus some material from extraneous sources will be found. But in most instances the material is of local origin. In true basal conglomerates, on the other hand, while the material is very frequently derived in large measure from the immediately subjacent formations, they also usually contain a small proportion of material from various foreign sources, and do not contain any material from the overlying formations, as may the autoclastic rocks.

(2) In an autoclastic rock, if the pebbles are closely examined they will in many cases be found to be less rounded than in a true basal conglomerate. If the belts of brecciation be followed for some distance a considerable variation will frequently be found in this respect, fragments being here well rounded and there very imperfectly rounded. The well-rounded fragments are concentrated, as are also the angular fragments. A basal conglomerate, on the other hand, has a considerable uniformity in the degree of the rounding of its pebbles in passing along the same horizon, but at the same place the large fragments may be angular and the small ones well rounded. In a basal conglomerate very near to the underlying formation many of the contained fragments may be angular, but in an extreme case the fragments of a basal conglomerate are upon the average usually not so angular as those of an autoclastic rock.

(3) In many cases the interstices of an autoclastic rock are filled with material of a vein-like character, whereas in a basal conglomerate the filling material is largely finer detritus. But sometimes, as in the case mentioned of a semi-indurated quartzite, the filling material of an autoclastic rock may be waterworn grains of sand, which have been separated by dynamic action, and are therefore indistinguishable from the ordinary matrix of a true conglomerate.

(4) In most instances a bed of autoclastic rock, if followed, may be traced into an ordinary brecciated or partly brecciated

form. A basal conglomerate, on the other hand, if followed along the strike and dip, may change its character, but it will be a gradual change into the ordinary mechanical sediments, whereas an autoclastic rock is likely to have very sudden variations in character.

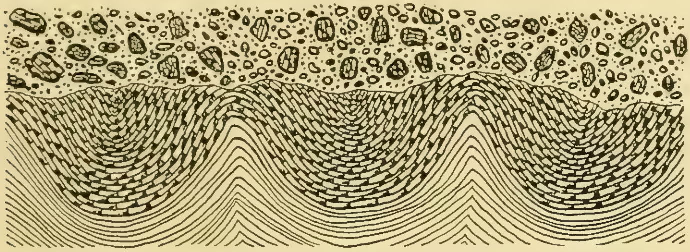

FIG. 17.—Chert breccia, an autoclastic rock resting upon truncated minor folds of limestone.

Using all of the above criteria, it is difficult in some cases to discriminate between an autoclastic rock and a true conglomerate. Usually, however, if an area be studied sufficiently long, and if the relations be examined closely a true judgment may be reached.

Autoclastic rocks are not likely to develop from shales and limestones, but if near enough to the surface even these rocks may become brecciated. As a consequence of orogenic movements, in the zone of combined fracture and flowage, where the alternate layers are thick, the shales and limestones may flow and the cherts and quartzites become brecciated. The brecciated and nonbrecciated layers, under these circumstances, may not become mingled to any considerable degree. Thus we may have a set of autoclastic rocks interstratified with layers which show no sign of brecciation. It may be that the plastic layers, as a result of the stress, may be minutely corrugated. The movement of the broken particles in the rigid layers against the crests and troughs of the folds may have truncated them. We might then have pseudo-conglomerates resting upon folded truncated layers (Fig. 17), and it might be concluded that there

is a structural break between the two, the inference being that one formation was folded and truncated before the overlying clastic formation was deposited upon it. This occurs in the Marquette district of Michigan.

Another case is as follows: A lower shale or grit may be overlain conformably by a sandstone. By cementation these formations may become indurated; the grit into graywacke, and the sandstone into quartzite. After this an orogenic movement may develop cross cleavage or cross fissility in the softer, lower formation, the secondary structure abutting against and sharply terminating at the overlying quartzite. The same movement may develop a pseudo-conglomerate in the overlying formation. In the later stages of the process the differential movement may tear off fragments of the lower slate or schist and include them with the broken, harder formation. Such a pseudo-conglomerate simulates to a remarkable degree a basal conglomerate resting unconformably upon an earlier series, in which it might be supposed that the secondary structure was produced before the overlying formation was deposited. Exactly these relations obtain within the Ajibik quartzite formation of the Lower Marquette series, northeast of Palmer. At first it was supposed that the pseudo-conglomerate was basal and marked an unconformity, and it was only after the locality was repeatedly visited and studied in the utmost detail that the true relations between the two formations were discovered.

Similar phenomena may occur between formations different from those above described, in which the inferior formation is weaker than the superior formation.

As another illustration of the great difficulty in sometimes distinguishing between the two, a case in the Adirondacks may be cited in which a thick formation of gneiss is overlain by a bed of crystalline limestone containing interlaminated smaller beds of gneiss. The whole series has been closely folded. The gneiss, as a result of the folding, is closely corrugated, and to a certain extent its upper folds are truncated by the shearing action. The limestone has acted like a fluidal substance, accom-

modating itself easily to its new position, and by recrystallization has taken on a massive character. The thin belts of gneiss within the limestone have been broken to fragments. The fragments in the limestone matrix have ground against one another until they became well rounded. They are disseminated through the limestone. As the layers of gneiss are thicker and more numerous near the base of the limestone, this part of the formation appears as a limestone containing numerous bowlders and smaller fragments of gneiss resting upon a gneiss formation. Thus an unconformable contact was inferred when the area was first examined, but an extended and close examination of the region showed all stages of transition, from the phase of the rock which appeared to be a true conglomerate to that in which the thin layers of gneiss are interstratified with limestone. Similar phenomena have been observed in the Original Laurentian area and in the Marquette district of Michigan.

C. R. VAN HISE.

EDITORIAL.

It is important to geologists to know to what extent the glacial drift of northern latitudes owes its thickness to the secular decay of the rocks, and also whether we can use, in high latitudes where decomposed rock material has been removed by ice, data collected on the subject of rock decomposition in the tropics where it has not been so disturbed. In the paper by Professor Derby in the present number, he is disposed to take a conservative view of the subject of rock decomposition in Brazil; and Professor Derby's long residence in that country entitles his opinion to much weight.

Our studies of the subject of rock decay in Brazil were begun and carried on under the impression, probably received from the writings of Agassiz, Darwin, and others, that it was extraordinary and the paper on the "Decomposition of Rocks in Brazil" cited by Derby was given as a record of the facts and an attempt to explain them. It is but just to confess, however, that when the results were brought together we were not as much impressed by them as we had expected to be. And the more we see of decay in temperate regions, especially in unglaciated regions of granitoid rocks, the less striking does the decay of rocks in Brazil appear. In California, in Virginia, in the great kaolin pits of St. Yrieux, France, and in the Guadarrama Mountains of Spain we have seen many examples of the decay of granites and gneisses that are very nearly as deep as any we have seen in Brazil.

The unequal decay of rocks, and even its absence, was not overlooked in the article referred to by Derby. Mention should have been made at that place of a letter by Dr. A. R. C. Selwyn, published in the *Geological Magazine* (1877, p. 94) where he calls attention to this unequal decay of rocks in Brazil and Australia as a possible explanation of glacial lake basins in the north.

The possibility of faulting in the Serra do Mar is a question of importance in connection with the subject of rock decomposition in that region, but too little is known of the facts to admit of anything more than speculation on this subject. The region is covered by a dense tangle of forest and undergrowth that render detailed examination extremely difficult, and this difficulty is greatly increased by the decomposition of the rocks and by the lack of artificial exposure that would help to an understanding of the structure.

Derby thinks the whole question is covered by the proposition of Pumpelly that, other things being equal, the depth of rock decay is due to time and to the permeability and solubility of the constituents. Such a statement admits of no question. But the difficulty with such a way of putting it is that it is simply another way of saying that time, permeability, and solubility are elements of rock decay, for, as to other things being equal, they seldom or never are equal, even in the same region, or in the same rocks. It might be as truly said that other things being equal the rate of decay is determined by the color of the rocks, by their dip or by the dip of their surfaces, or even by the direction of the prevailing winds with reference to their dip. The agencies and processes of rock decomposition are complex.

We are of the opinion that a comprehensive knowledge of this subject is to be had in a study, not of road and railway cuts, but of the mineralogical changes to be found in deep mines and tunnels. The susceptibility to alterations of copper and iron sulphides to sulphates, carbonates, oxides, silicates, etc., offer a delicate test of the penetration of the agencies of decomposition. Penrose cites cases of the alteration of such ores to the depths of 600, 1000 and even 1500 feet. (JOUR. GEOL. II, 1894, p. 295.)

J. C. B.

Reviews.

Greenland Ice Fields and Life in the North Atlantic, with a New Discussion of the Causes of the Ice Age. By G. Frederick Wright, D.D., LL.D., F.G.S.A., author of "The Ice Age in North America," etc., and Warren Upham, A.M., F.G.S.A., late of the Geological Survey of New Hampshire, Minnesota, and the United States. New York: D. Appleton & Company, 1896.

The contributions of the two authors of this volume are essentially equal, the one having prepared eight and the other seven of its fifteen chapters. The names of both authors appear duly on the title page as above indicated, but only the name of Wright appears on the cover. The book takes its point of departure from the unfortunate Miranda Expedition which, after a series of minor mishaps, met with a decisive disaster off the harbor of Sukkertoppen in South Greenland on the 9th of August, 1894. The senior author was a member of that expedition and spent two weeks on the coast of southern Greenland. The junior author has never visited Greenland. With this scant basis of personal observation it is obvious that the work is essentially a compilation so far as its main theme is concerned. The only original contributions to the ice fields of Greenland are the brief observations of Professor Wright on the local glaciers back of Sukkertoppen. The designation of the glaciers as local is not the author's. On the contrary, Professor Wright ends an enthusiastic description of the principal one visited by him, near Ikamiut, with this climax: "This was verily a part of the inland ice" (p. 94). As a further enforcement of this conception he introduces a map, here reproduced in part (Fig. 1), which represents a tongue of ice flowing along the mountainous divide between the South Isortok and the Kangerdlugsuatsiak fiords in brave negligence of the obstructing peaks and soliciting fiords. It may be interesting to compare this with the accompanying photographic reproduction of the British Admiralty chart (based on the Danish Government Surveys) of

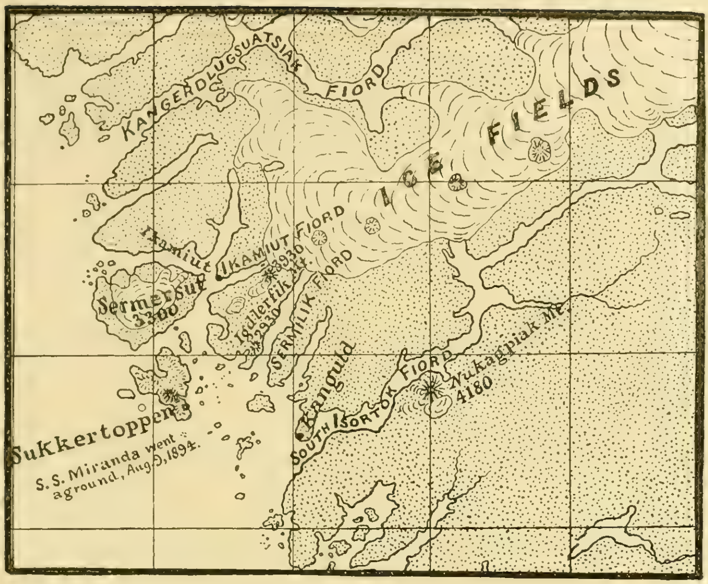

FIG. 1.— Section of the map of the author.

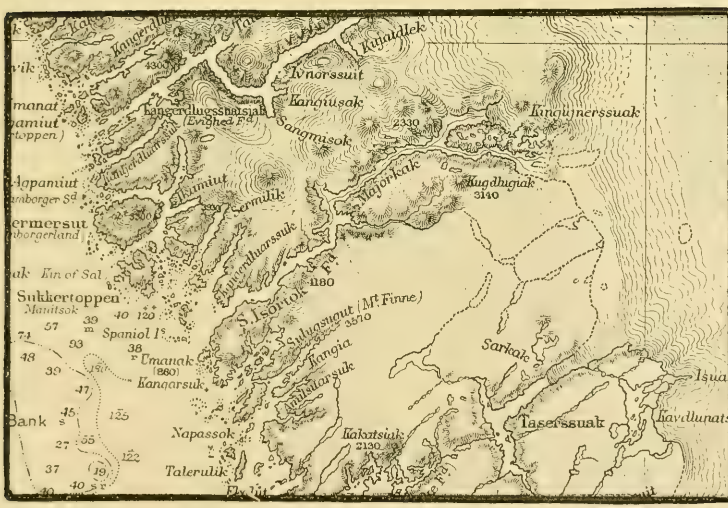

FIG. 2.— Section of the Admiralty Chart.

the same tract (Fig. 2). On it the glaciers appear as the offspring of the snow fields of the mountains that crown the divide and they flow rationally from their local gathering grounds in various directions in due respect to gravitation and the usual habit of glaciers. The glacier near Ikamiut is represented as descending from the snowfield of a neighboring mountain and as finding its source some two-score miles away from the edge of the inland ice which the author nowhere more nearly approached.

Aside from scenic and geographic features, there are two observations of the author that bear on general glaciology: "These glaciers on the south side are all of them thicker near the base of the mountain than in their higher levels. Indeed, they seem to run down like cold tar and to thicken at the base as a stiff semi-fluid would under the action of gravity" (p. 95). "Another phenomenon illustrating the nature of the movement going on in great glaciers was seen here to special advantage. Where the great ice-sheet abutted against the mountain which divided its front into two portions it was pushed up by the momentum of the movement so as to be two or three hundred feet higher at the base of the mountain than it was a mile back. Indeed, a half mile or so back there was a distinct depression in the glacier with the ice higher all around it. It was just such a depression as is made where a current of water is obstructed by some obstacle; the current pushes some distance up the obstruction and then breaks over the sides to go around it; but ice, being much less fluid than water, moves off in larger swells and more gradual curves" (p. 95). A simple computation of the momentum of the glacier and of the ratio of this to basal friction is sufficient to reveal the absurdity of attributing this phenomenon to momentum. There is a special infelicity in citing fluidal action by way of illustration, since it is quite clear that it is the element of *rigidity* in the ice, acted upon by pressure from behind, that produced the upthrust.

Perhaps the observations of Professor Wright on icebergs should be included among the original contributions of the volume to the glacial phenomena of Greenland. Icebergs were encountered — literally in one case — in large numbers and quite unusual dimensions and they are very graphically described. The one with which the Miranda collided is said to have "towered hundreds of feet above us" (p. 6), and another was estimated "to have pinnacles which rose more than 700 feet above the water" (p. 3). In the minds of those

who are familiar with the limited depths of the fiords and bays from which the icebergs issue, these towering dimensions will doubtless awaken skepticism, notwithstanding the appeal made in the latter case to an extended base. Professor Wright contributes some interesting observations on the coast of Labrador, accompanied by excellent views.

The chapters written by Professor Wright relate to the *Ice of the Labrador Current*, *The Coast of Labrador*, *Spitzbergen Ice in Davis Strait*, *Excursions on the Coast of Greenland*, *The Coast in Detail*, *The Eskimos of the North Atlantic*, *Europeans in Greenland*, and the *Summary and Conclusion*.

Mr. Upham contributes the chapters on *The Plants of Greenland*, *The Animals of Greenland*, *Explorations of the Inland Ice of Greenland*, *Comparisons of Present and Pleistocene Ice-sheets*, *Pleistocene Changes of Level around the Basin of the North Atlantic*, *The Causes of the Ice Age*, and the *Stages of the Ice Age in North America and Europe*. These chapters contain a large amount of matter brought together from diverse sources and will prove very serviceable to those who have no convenient access to the original literature, or who lack the time to make use of it. The non-geological part of it we must leave to the botanists and zoölogists. The summary of explorations of the inland ice embraces numerous and extended extracts from the writings of the several investigators of the region, knit together by explanatory matter and accompanied by illustrations from Jensen and Chamberlin and a map prepared by the author.

The chapters which relate to the Pleistocene ice-sheet and the causes and stages of the Ice Age are essentially a reproduction, in a revised form, of the author's recent papers on these subjects in various scientific publications and are so familiar to geologists as not to need special review here. Mr. Upham brings out into sharper definition than before his acceptance of the doctrine of notable ice stages. He defines and maps the Warren, Toronto, Iroquois and St. Lawrence stages in addition to the more generally recognized Kansan, Iowan and Wisconsin stages, and applies the nomenclature of the last group to Europe. It is to be observed, however, that the mapping, if not the discrimination, of the four added stages, is almost wholly hypothetical. Mr. Upham still prefers to interpret these stages as phases of a single period of glaciation. The definite recognition

of distinct stages, however, removes from the advocacy of the doctrine of "unity" the gravest objection which has heretofore lain against it, viz., neglect of important discriminations and confusion of formations diverse in age and nature. The degree of separation of the glacial stages recognized by Mr. Upham finds its maximum illustration in the retreat of the ice after the Kansan stage for a distance of 500 miles and its readvance about 350 miles, an oscillation which, if applied to Greenland, would eliminate and reproduce its ice-sheet.

Mr. Upham still urges the hypothesis of elevation as the chief cause of the Pleistocene glaciation. It seems not a little infelicitous to urge this doctrine in a work on Greenland, since the testimony of that region weighs heavily against the doctrine. At intervals along a thousand miles of the western coast it was observed by the present writer that a notable part of the mountainous border is rugged and angular and betrays no evidence of ever having been overridden by inland ice. A small driftless area was also discovered on the very border of the inland ice on Bowdoin Bay between latitudes 77° and 78° which shows more unequivocally that there has never been a general extension of the Greenland ice-sheet westward much beyond its present outline. The evidence of former elevation is as pronounced in Greenland as in any part of the northern hemisphere. It appears, therefore, that in this land of glaciers *par excellence*, the former elevation of two or three thousand feet or more was not accompanied by any great extension of glaciation, if indeed it was accompanied by any general glaciation at all. It appears, therefore, that the epeirogenic theory is weak on its most radical point—coincidence of elevation with glaciation—in its most promising region. To the writer it seems unfortunate that the public should be so industriously indoctrinated in a theory of the cause of the Ice Age which encounters such serious and seemingly fatal testimony in the very home of glaciation.

T. C. C.

Ice-Work, Present and Past. By T. G. BONNEY. International Scientific Series. New York: D. Appleton & Company.

FOR the past twenty years the author has written chiefly on petrological subjects. Many of his earlier papers, however, dealt with ice and its work, and this book is an expression of the revival of that

earlier interest. He assigns as an especial occasion for adding another to the treatises on glaciology the predisposition of most authors to advocate some particular interpretation of the facts rather than to describe the facts themselves. He has made it his endeavor to follow the example of a judge rather than an advocate. To the extent of maintaining a judicial spirit he seems to have been quite successful. But in assuming to perform the functions of a judge he appears to have overlooked a prerequisite quite as essential as impartiality, viz., an intimate knowledge of the law and the facts in the case. Twenty years of specialization in petrology is scarcely an ideal preparation for donning the judicial ermine in the glacial *cause célèbre.* The inevitable lack of close familiarity with the glacial investigations of recent years is displayed throughout the work. It has led the author to depend upon other compilations, and these not always the best. As a result much of the matter does not come to the reader even at second hand. Haworth and Wright were evidently very serviceable in the preparation of the book. In some notable instances a compiler is quoted as authority instead of the original investigator, even when the original literature is easily accessible and well known. Further currency is given to some things which were doubtful at the outset and which have since passed beyond serious consideration, for example, the alleged benches 1700 feet above the surface of the Great Lakes, and the hypothetical Lake Ohio, based on the hypothetical Cincinnati ice dam. The lack of an intimate command of the subject also appears in the author's inability to adjudicate theories when it is quite possible to do so. This is pointedly illustrated in his summation of the hypotheses respecting the formation of kames and eskers, in which he says: "On the whole, rivers, swollen by melting ice and snow, seem the more probable cause, but it is still open to discussion whether kames and eskers are to be regarded as monuments of sub-glacial torrents or as marking the path of streams which, in the latter part of the glacial epoch, cut their way through expanses of soft and fine material which subsequently have been removed" (p. 168). The latter alternative is wholly beyond seriou consideration, as it is altogether inapplicable to the phenomena.

The work is divided into three sections, Part I, relating to the existing evidence as found in Alpine glaciers and in Arctic and Antarctic ice-sheets: Part II, relating to traces of the glacial epoch, in which lake basins and their relations to glaciers, the parallel roads of

Glen Roy, ice-work in Great Britain and Ireland, and in Europe and other parts of the world constitute the leading themes ; and Part III, relating to theoretical questions, especially the temperature of the glacial epoch, its possible causes, and the number of epochs. The discussion of the temperature of the glacial epoch embraces the largest amount of measurably unfamiliar material and is perhaps to be regarded as the most valuable part of the book. The description of alpine and polar glaciers is not brought up to date and is sadly lacking in suitable illustrations, for which abundant material now exists. In the discussion of the traces of the glacial epoch disproportionate attention is given to the excavation of lake basins, to the exclusion of erosive work in other lines quite as important, and the author's impartiality is not as well sustained here as elsewhere. Very much attention is given to the glacial phenomena of Great Britain, and relatively scant attention to that of Europe and America. It is natural that an English writer, presumably having in mind chiefly the English public, should give much prominence to home phenomena, but obviously in a work which takes on so comprehensive a title and is published as a part of an international series, the distribution of attention should be somewhat proportional to the development of the phenomena. In the discussion of the possible causes of the glacial epoch the author's judicial attitude appears to the best advantage. We think he is correct in concluding that "the glacial epoch has not yet received any satisfactory explanation." The literary style of the work is excellent, the language being clear and quite free from rhetorical coloration. The illustrations are not only scant and poor, but the selection is unfortunate in several cases, some of them being unworthy of reproduction.

T. C. C.

General Relations of the Granitic Rocks in the Middle Atlantic Piedmont Plateau, by G. H. Williams. (Fifteenth Annual Report, U. S. Geol. Surv., pp. 657–684.)

The Piedmont plateau is classic ground in American geology. Within its limits many of the important problems of American science have been worked out, but by far the larger number of questions which it presents are yet unanswered. It is a region of great complexity. From the holocrystalline, undoubted igneous masses of the eastern border to the unchanged sedimentaries further west there is

every gradation. Dynamic metamorphism, contact phenomena, folds, faults, thrusts, shearing, and foliation are all presented over and over again. The unraveling of the history of such a region must be the result of long and patient detailed work. Only after most elaborate field and laboratory investigations can facts of broad bearing be enunciated.

It was in this region that the late Professor Williams did by far the larger portion of his life's work, and he had a knowledge of it which no other man has ever had. The results of many of his studies have been already published, and so we have his papers on the gabbros and his beautiful map of the Baltimore region. The larger generalizations which only come after many years of study were in many cases not yet completely formulated, and in others, while formulated, were unpublished.

In the present paper we have Professor Williams' views as to the origin of the granites and pegmatites. As an introduction to the former he has summarized the criteria for the recognition of ancient plutonic rocks in highly metamorphosed terraines ; a summary which is most valuable, though marred by the incompleteness of the references. Among other field evidences of the igneous origin of doubtful rock masses are enumerated the presence of radiating apophyses, foreign inclusions, and contact zones. That these may be obscured is recognized, and in the recognition of altered eruptives the author evidently relies largely upon chemical and petrographical evidence. The test formulated by Rosenbusch and depending upon the definite or indefinite character of the chemical composition of the rock has been applied by Professor Williams to certain of the gneisses of the region. Faint traces of structure originally igneous are found in rocks which are quite completely changed. The development of certain minerals is regarded as strongly suggestive of contact metamorphism. The determination of the relative ages of intrusions in such a region must rest largely upon contact phenomena. Often an eruption may prove to be anterior or posterior to some period of strong metamorphism, and hence its relative place in the history of the region may be known. It is by means of such evidence that the origin of the granite masses has been tested. The detailed observations upon granites of the central portion of the state are recorded by Dr. Keyes, and in general it may be stated that with few exceptions the granites of the entire region may be proved to be of igneous

origin. A very interesting table showing the chemical composition of the ancient igneous rocks of Maryland accompanies this paper.

With regard to the pegmatites, evidence is presented for the belief that very many of them are eruptive; though it is not thought that all will be found to have had that origin. The evidence that they are eruptive is based upon the agreement in composition between the granites and the pegmatites, the greater abundance of the latter near granite masses, their independence as regards the character of the rocks they cross, their relations to the adjoining rock, and the fact that as a rule these pegmatites are neither drusy nor symmetrically banded. The fact that in spite of the essential identity between the composition of the pegmatites and the granites there are certain differences, is interpreted as pointing to somewhat different conditions of formation, in which there was a greater activity of the mineralizing agencies.

The author agreed closely with De Beaumont, Lehmann, and Brögger in his conception of the process of the origin of these pegmatites. They are interpreted "as the products of the residual, and therefore most acid, portion of a granite magma highly charged with water and other mineralizing agents, in a state intermediate between fusion and solution, interjected into fissures and there crystallized in very coarse-grained aggregates, not necessarily through any great slowness of this process, but rather in virtue of the aid to crystallization afforded by the abundance of mineralizers present."

H. F. Bain.

Sketch of the Geology of the San Francisco Peninsula, by Andrew C. Lawson. Fifteenth Ann. Rep. U. S. Geol. Surv., pp. 399–476. Pls. V–XII.

This paper is a valuable contribution to the literature of the Pacific coast. The area considered lies between the Pacific Ocean and San Francisco Bay, and extends from the Golden Gate southward about twenty-one miles.

The work done reveals seven formations which, in their geological order, are: (1) Crystalline limestone; (2) Montara granite; (3) The Franciscan series; (4) Sandstone of Tejon (?) age; (5) The Monterey series; (6) The Merced series; (7) The Terrace formations.

The Montara granite is exposed along the Pacific shore about one

mile south of Point San Pedro, or about sixteen miles south of the most northern point of the peninsula. At its exposure along the shore line it is overlain by the basal conglomerate of the Franciscan series, but a short distance from shore it becomes the surface rock and covers an elliptical area whose major axis is ten miles, extending in a northwest and southeast direction, and whose minor axis is four miles. That this formation is newer than the crystalline limestone is indicated by the fact that "farther south in the Santa Cruz range, the same granite is found in irruptive contact with pre-existing terranes among which crystalline limestone or marble is prominent," and also by the fact that a mass of marble was found embedded in the granite within the area considered.

The petrographic character of the Montara granite leads to the conclusion that it cooled as a batholite. The mantle, which consisted in part of the crystalline limestone was almost entirely removed before the Franciscan series were deposited, which in turn were removed before the Tejon-like sandstones were laid down.

The Franciscan series occupy the greater part of the peninsula, and are separated by the Merced Valley into a northern and a southern area. Petrographically the series are divided into (1) A basal formation; (2) The San Francisco sandstone; (3) Foraminiferal limestone; (4) Radiolarian cherts; (5) Volcanic rocks. Of these the most important are the San Francisco sandstone and the Radiolarian cherts.

The San Francisco sandstone is that of the early writers. It forms the bulk of the sedimentary rock of the series. Its original color is a greenish or bluish gray, but it easily weathers to a yellowish brown. In the field it presents a massive aspect "due to the thickness of the beds and the obscurity of the bedding planes."

The Foraminiferal limestone is described as having "a fairly constant petrographic character throughout the terrane, although it is found at more than one horizon." It is generally traversed by two sets of veins — calcitic and siliceous. The latter are often parallel to the bedding of the limestone, and may be contemporaneous with it. The limestone itself is thought to be a chemical precipitate.

The Radiolarian cherts are of a dull reddish-brown color, are several hundred feet thick, composed of sheets of chert from one to four inches thick alternating with partings of shale, and occur locally in lens-like masses. Petrographically they occur as true jaspers, as rocks of a flinty or hornstone character, as rocks that are easily scratched

with a knife, and sometimes as quartz rock which resembles vein quartz. They vary from those which are amorphous silica to those which are chiefly holocrystalline aggregates of quartz granules. The mineralogical character of the amorphous silica is doubtful. It is perfectly isotropic, but contains a less amount of water and is harder than opal.

Concerning the origin of the Radiolarian cherts, Professor Lawson advances the theory that they are chemical precipitates from springs, and supports the theory by the fact that they occur locally and in lens-like masses. In working over the field in San Francisco and vicinity, it has seemed to the present writer that these rocks were once wide-spread. This is indicated by the small fragments of chert almost everywhere found on the surface. Their present local occurrence is not remarkable when it is remembered that they have suffered at least two periods of erosion — that preceding the deposition of the Merced series, and the present one. There is also some evidence of an unconformity between the lower portion of this series and the bed of sandstone which separates it into two parts.

The serpentine of the area occurs with the Franciscan series, and is in three tracts extending from northwest to southeast parallel with the strike of the rocks. One of these tracts is north of the Merced Valley, and two of them south. That on the north side occurs in three large masses which are described as the Presidio laccolite, the Potrero laccolite, and Hunters Point laccolite. These are probably expansions in a dike of serpentine which extends from Fort Point to Hunters Point, a distance of about ten miles. They are in places one and one-half miles wide, and reach a thickness of 500 feet. Both the Presidio mass and the Potrero mass consist of two lenses of serpentine separated by sandstone.

The writer calls attention to the great number of masses of "medium-grained, dark, greenish gray rock" in the serpentine of Potrero and Hunters Point. These have been shown to belong to the hypersthene diabases, and in their more altered forms to the epidiorites, and are thought to be inclusions in the serpentine.

The present writer is not familiar with either of the two serpentine tracts on the south side of Merced Valley, but they are described as in all essentials similar to that on the north side.

Professor Lawson finds nothing from either microscopic study or field observations to support the theory that this serpentine has originated from sandstone, but concludes that "the various conditions

and aspects assumed by the rock are functions of a process of chemical alteration from peridotite or pyroxenite and a mechanical disintegration of the rock thus altered."

The rocks of the Merced series rest unconformably upon the Franciscan series, and occur in two areas, one on either side of Montara Mountain. The series consists chiefly of soft sandstone. There are, however, among the series, hard shell beds firmly cemented, and soft shell beds, uncemented; hard beds of gravel, lignitic beds, and a bed of volcanic ash. The northern of the two areas dips to the northeast, and is exposed along the beach for a distance of 20,000 feet. It is 5800 feet thick, and is the heaviest Pliocene deposit known in North America.

The most marked structural feature of the region consists of two fault blocks, both tilted to the northeast, and designated as the San Bruno block and the Montara block. It is this tilting of the Montara block that gives the Merced series its constant dip to the northeast.

That the San Bruno block is older than the Montara block is proved by the fact that the Merced series has all been removed from the former, as well as by the fact that its topography is more mature than the latter.

Two cycles of erosion are indicated on the San Bruno block — an early one which is manifested only above an altitude of 300 or 400 feet, and a later one which has modified the old topography. The modification of the old topography has been effected in two ways. The first is that due to atmospheric and stream agencies, the second to "destructive and constructive shore action at the various stages of the uplift." The crest of San Bruno Mountain is thought to be due to the same cause which determined the 1200-foot terrace on the higher Montara block; and the 750-foot terrace on San Bruno mountain is doubtless due to the same shore line that formed the 700-foot terrace on the Montara block.

On the Montara block there is only the later cycle of erosion manifested. During this time there were formed the two terraces above mentioned. These are well marked on the northeast slope, and less so on the southwest slope.

The consequent streams on the northeast slope of the Montara block which came into existence on its emergence from the ocean, became superimposed streams on reaching the hard terranes beneath the soft Merced series. Later, as a result of the longitudinal faulting, these

were changed into subsequent streams. As these developed, the superimposed consequent streams became atrophied, leaving only the lower part of the San Mateo Creek. "The remarkably straight valley of Crystal Spring and San Andreas is a magnificent example of a subsequent drainage system extending laterally along a fault in opposite directions normal to the original consequent drainage." Other excellent examples of captured and superimposed streams are mentioned.

Lake Merced, though in a structural valley, is considered a drowned valley of stream erosion. The bottom of the lake is ten feet below sea level, which demonstrates its recent submergence. Its access to the ocean was cut off by sand dunes which dammed up its channel till the water stood ten feet above tide.

The contrast between the ocean shore-line and that of the bay is noted. The former presents steep cliffs and sandy beaches due to the vigorous action of the waves, while the latter has a tidal marsh, in places some miles wide. This marsh may be due to the deposition of material from the bay water during the rainy season. The fact that the tidal marsh is perfectly level and the tidal streams reach back to its rear, indicates that there has been no very recent uplift. On the other hand there may have been a slow subsidence, during which the rate of deposition was equal to the subsidence.

The colored relief map accompanying the paper is worthy of special note for its elegance and effectiveness.

A. H. PURDUE.

ABSTRACTS.

University Geological Survey of Kansas. By ERASMUS HAWORTH AND ASSISTANTS. (Vol. I, 320 pp., pl. XLI. Topeka, 1896.)

This report covers the whole of the Carboniferous of the state and includes notes on various detailed sections across the area, studies of the stratigraphy and lists of characteristic fossils. Economic geologists will be especially interested in chapters XI and XII, relating to the coal and oil and gas fields. In all some twenty counties have produced more or less coal and the output for 1894 was valued at $4,889,-774.62. Nearly 90 per cent. of this was won from the Cherokee shales, the basal portion of the Coal Measures. Near the middle of these shales is the heaviest vein occurring in the state. It is known as the Weir City-Pittsburg coal. It outcrops to the southeast and dips northwest at a rate of about 17 feet per mile. It is remarkably uniform in thickness, averaging 40 inches with an occasional maximum of four feet or more. Thinner veins occur both in the Cherokee and other shale beds. The heating power of a number of Kansas coals as determined by Professor Blake of the State University ranges from 9.90 pounds of water evaporated per pound of coal, to 14.43; most of the coals evaporating from 12 to 13 pounds. In volatile matter Professor Bailey, also of the University, finds a range of from 35.32 to 46.14. The water ranges from 1.31 to 13.70 with the larger number of analyses below 7 per cent. The fixed carbon runs from 28.52 to 54.17 and the ash from 7.46 to 13.96.

Dr. Haworth thinks there are good reasons for believing that coal mining in Kansas will increase with comparative rapidity during coming years, and that the amount of coal present has been very greatly underestimated.

Gas and oil have been suspected to occur in the state since its first settlement, and from time to time wells of more or less volume have been opened up, till in 1890 a dozen towns and cities were principally or wholly supplied with light and fuel from these sources. The major development of the field has been in the last six years and has been brought about largely by the systematic prospecting carried on by the large eastern companies. At present gas is used wholly or partially in

Wyandotte, Paola, Ossawatomie, Fulton, Iola, Humboldt, Cherryville, Neodesha, Independence and Coffeyville, and has been obtained in more limited quantities at Fort Scott, Girard, Pittsburg and elsewhere. Oil is obtained in considerable quantities at Peru, Neodesha, Thayer, Independence, Ossawatomie and elsewhere. Quite flattering results were being obtained by prospectors in the early months of the present year when the report went to press. The field, as now outlined, includes 8500 square miles and is approximately bounded as follows: From Kansas City draw a line to Lawrence and from the latter point continue it through to Sedan in Chautauqua county. With the exception of about 500 square miles in the southeast, the area included is all within the field; not a single county within these limits having failed to produce oil or gas or both. Nine-tenths of the flow has come from the sandstones found in the Cherokee shales, though each of the shale beds from the Mississippian to the Lane shales has proven more or less productive. The flows are not exceptionally heavy, though there are strong wells at Neodesha and the Palmer well at Iola yields seven million cubic feet of gas per day. But few paying wells are known which are more than 900 feet deep and many good wells are less than 600. The details of the anticlinals and synclinals present in the field are too imperfectly known to allow any general conclusions as to their influence to be drawn. The Paola well is in one of the greatest synclinals present in the state. In general, structure seems to have had but slight influence upon the collection of the gas, texture being far more potent. The gas and oil are of organic and probably vegetable origin. They are derived from the bituminous shales and collected in the more porous intercalated sand beds. Probably this accounts for the fact that they are more uniformly disseminated in the Kansas field than in any other yet developed in America. Dr. Haworth thinks there is good reason for hoping that the oil and gas industry of the state will ultimately assume considerable proportions even compared with the same industry in the eastern states.

H. F. B.

Till frågan om lommalerans ålder (Concerning the Age of the Lomma clay). Af Gerard de Geer. Sveriges geologiska undersökning, Afhandlingar och uppsatser, no. 155; Stockholm, 1895.

The author replies to the arguments put forth by Holst and Moberg against evidence for interglacial deposits in Sweden. He calls atten-

tion to the fact that he has not regarded the reference of the Lomma clay to the interglacial river clay (hvitålera) as being certain and beyond dispute. While his reserve in this respect has been correctly stated by other authors, it has not been indicated by Holst and Moberg. As to the argument made by these gentlemen that a later glacier would have left a heavier moraine resting on the Lomma clay, it is urged that no such moraines have been left by the ice in a great many other places, where the bed-rock is now in view, nor are such moraines now found over extensive areas in Germany and Denmark, where they are known to have been removed by erosion. The undisturbed bedding of the Lomma clay does not preclude the possibility of later glaciers overriding it, for underlying soft beds are not always disturbed under such conditions. As to the fossils which have been found in this clay (*gadus polaris*, *coscinodiscus*, and a number of foraminifera) the author shows that there is reason to believe that the foraminifera have been washed out from the subjacent moraine, and hence may belong to an earlier period. Hence these fossils do not indicate anything with certainty as to the climate obtaining when the clay was deposited. The age of the Lomma clay must still be left an open question. The author does not regard this circumstance as having any important bearing on the hypothesis of a multiple glacial age as applied to Swedish territory. He inclines to the view that the Lomma clay and the Yoldia clay both belong to a horizon between the drift of the earlier glaciation and the drift of the Baltic ice-sheet, but he leaves the question unsettled as to the climatic conditions indicated by biotic evidence. To distinguish such undetermined deposits as these from other beds which are with certainty known to be interglacial, the author applies to the former the name *intra*glacial.

J. A. U.

Om strandliniens förskjutning vid våra insjöar. (On the Displacement of the Shoreline of our Inland Lakes.) By Gerard de Geer, Sveriges geologiska undersökning, Afhandlingar och uppsatser; no. 141, pp. 15.

As regards the displacement of the shoreline, the author divides the lakes of the glaciated country about the Baltic Sea into two classes: one including such lakes as have their outlets in the direction of least elevation, and the other including such as have their outlets in the direction of greatest elevation. Nearly all of the lakes in the high-

land of Småland belong to the former class and attention is called to the fact that extensive deposits of clays and marls occur skirting the north shores of these lakes. This indicates that the basins have been tilted to the south. The old lake bottoms have been raised above the water, on the north, and the lakes have been partially emptied. Deposits of sand, now covered by peat, north of the lakes Bolmen and Vidöstern indicate that these lakes have been reduced to about one-half of their original size by this process. It is believed that these lakes lie outside of the latest glacial limits, and the calcareous nature of the clays indicates that these are sediments brought down by glacial streams. The deltas of Klarelfven and Glommen, running into the raised ends of lakes Venern and Öieren, rise above the present level of the water in these lakes. The tilting of Lake Venern from north to south is believed to have been about 13^{m}.

Among the lakes which have been tilted away from their outlets, Stora Le and Vettern are mentioned. Stora Le is about fifty times as long as it is wide and its axis lies in the direction of the gradient of the differential elevation of the region. It appears that since the time this lake was separated from the sea by the barrier over which its outlet now runs, the north end of its basin has been elevated 101^{m}, while the south end has been raised only 92^{m}. Marked cliffs of erosion, submerged deltas, and lagoons indicate a relative sinking of the south end of the basin. It is likely that the displacement of the water level at this place amounts to 9^{m}. From like evidence it appears that the surface of the water in the south end of Lake Vettern has risen 10^{m} since the time this lake was united with the sea.

The last part of the paper touches on the evidences of displacement of the basin of the Ancylus Lake, a great body of fresh water which at one time occupied the basin of the Baltic Sea. The presence of arctic land plants in deposits on the shores of Kattegat renders it probable that this channel was closed at the time an arctic climate yet prevailed. The outlet of the Ancylus lake at that time was most likely over the depressions near Karlsberg or Örebro, north of Lake Vettern. In the south part of the Baltic basin submarine peat bogs show that part of this country has at one time had an elevation of 30^{m} above its present altitude. By a lifting of the north end of the Ancylus basin, the water was displaced to the south, until it made its escape through Öresund. When this lake reached its widest extent, it probably covered an area of $570{,}000^{km}$, exceeding in size all known

bodies of fresh water. Our present knowledge of the changes in level in the Baltic region is very incomplete, and the author urges the importance of more observations bearing on the subject. He is of the opinion that a close study of the changes in the shorelines of many other lakes will give important results in this direction. J. A. U.

The Search for the North Pole. By EVELYN BRIGGS BALDWIN. Published by the author, Chicago, Ill.

The author was meteorologist to the second Peary expedition and spent the year 1893–4 in northern Greenland. The severe conditions that limited the success of that expedition did not quench Mr. Baldwin's ardor for Arctic work, and this book has been prepared as an expression of that interest and as an aid to the necessary means for further enterprises. Its purpose is to awaken a wider interest in northern exploration, to remove erroneous impressions popularly entertained respecting it, and, if haply it may so be, to evoke aid for its continued prosecution.

The attempt of the book is to give a summary history of all Arctic expeditions. It is not confined to those whose chief object was to reach the pole. In this respect the book is broader than its title. The selection of matter has been made with a view to popular interest, and it is to be judged on that basis. It makes no pretension to a discussion of the scientific problems of the north, although matters of scientific interest are woven into the narrative so far as thought consistent with its popular interest. In the choice of extracts from the various narratives there has been only a limited yielding to the allurements of florid coloration, exaggerated heroism and morbid sensationalism which characterize so much of Arctic literature. It is a plain, straightforward, very readable story of a series of remarkable enterprises. It is probably the most complete compilation, within like limits, that has yet been made. T. C. C.

Iowa Geological Survey, Vol. V, Annual Report, 1895, 452 pp., 14 plates, 7 maps. Des Moines, 1896.

In the report upon Jones county Professor Calvin divides the Niagara series into the Delaware, Le Claire, Anamosa and Bertram stages. Of these the Le Claire is of considerable interest in that the

limestones composing it stand at a high angle, not as a result of folding but because of the conditions of deposition which seem to have been much the same as lead to cross-bedding in sandstones. Below the Le Claire is the reef rock of the Delaware, while above are the fine-grained building stones of the Anamosa. The drift deposits of the county include the Kansan and Iowan drift sheets, certain water-laid interglacial beds, the loess and the alluvium. Jones county is near the drift border and the puzzling anomalies of topography characteristic of that region are well developed.

In Boone county Dr. Beyer treats a region lying wholly within the Coal Measures and wholly within the area covered by the Wisconsin drift. The newness of the topography, which has been developed in post-Wisconsin time is striking. The Des Moines river runs through a deep narrow trench which follows the crest of a preglacial ridge. The appearance of the Gary moraine is well shown in Plate IV and the area covered by it is indicated on the map of the superficial deposits of the county which is the first drift map published by the Iowa Survey.

Warren county also is underlain entirely by the Coal Measures. In several detailed sections across the county Professor J. L. Tilton has illustrated their lithological character and structure. They are covered by the Kansan drift, which is in turn mantled by the loess-silt of southern Iowa. The main rivers of the county are considered to be of preglacial age. North Middle and South rivers are thought to have originally flowed southwest into the Cretaceous sea. They were reversed by the post-Cretaceous earth movements and now drain into the Des Moines, a subsequent stream developed along the strike of soft strata.

In Woodbury county there are exposures of the Cretaceous, including the Dakota and Colorado, certain sand beds called the Riverside sands and which, while of uncertain age, are considered to represent the "latest Pliocene or earliest Pleistocene," the Kansan drift, the loess and the alluvium. The Cretaceous beds have an important historical interest, and the loess is of great thickness and quite characteristically developed. Certain interloessial beds of drift are interpreted as the result of berg ice and considered as indicative of a close relationship between the loess and the Wisconsin ice; a relationship which later studies in adjacent regions do not seem to confirm.

The studies in Washington county are a continuation of those

carried on in Mahaska and Keokuk counties and reported upon in Volume IV. The Coal Measure areas are more limited, the areal development of the Augusta is greater, and the Kinderhook comes in. The latter is described as being made up of the Wassonville limestone, English River gritstone and Maple Mill shale, of which the latter may possibly be at once the upper continuation of the Devonian and the downward extension of the Carboniferous. The close relationship between the two systems is emphasized. The Pleistocene beds include the Kansan drift, loess-silt and the alluvium. The Iowan does not extend into the county and the loess-silt is an extension of the fossiliferous loess of the Iowan drift border.

Appanoose county is of interest in that the Coal Measures show an unusually regular phase of development. The Appanoose beds, as they have been called, include limestone, shales and a coal seam, which maintain their thickness and general character throughout an area of about 1500 square miles in Iowa and Missouri. The conditions of deposition were remarkably uniform and indicate a considerable change from the turbulent and rapidly varying conditions usual in the Des Moines terrane. It has been possible in this county to accurately map the coal-bearing area and a section from Ottumwa southwest indicates the probable presence of lower coal beds, a fact of considerable economic import. The Pleistocene problems are much the same as in Warren and Washington counties and the beds present are the continuations of those described in those counties.

H. F. B.

Monoclinic Pyroxenes of New York State. HEINRICH RIES. (Cont. Min. Dept. Columbia Univ., Vol. VI, No. 6; Annals New York Acad. Sci., Vol. IX, pp. 124–178, pls. XIII–XVI. New York, 1896.)

The pyroxenes of New York occur in the following conditions: (1) as primary constituents of igneous rocks; (2) along the contact zones between the limestones and intrusive rocks; (3) in crystalline limestones in areas of regional metamorphism; (4) associated with iron ore bodies. The present paper includes results of crystallographic, chemical and optical investigations of all the monoclinic pyroxenes of the state, with the exception of Wollastonite. The crystallographic forms found to occur are few in number, but the combinations and the relative development of the faces are in most instances quite character-

istic of the locality. These peculiarities are mentioned under the detailed descriptions of the different localities which follow the more general portion of the paper. Mr. Ries' investigation of the relation between the optical and chemical properties of the pyroxenes, shows that the extinction angle does not increase with the percentage of FeO, thus disagreeing with Wiik's results, although the latter himself found several exceptions to his rule. Comparing the extinction angle with the corresponding sums of the ferrous and ferric iron gives no better results. If, however, the combined percentages of FeO, Fe_2O_3 and Al_2O_3 be taken, a more regular series is obtained. If, furthermore, those containing less than 3 per cent. of Al_2O_3 be excluded from the list as more properly belonging to Diopside, a still better series is obtained, though not even then is the series a perfectly regular one. The results of etching agree very closely with those obtained by Wulfing and by Greim. In the chemical investigation Mr. Ries has attempted to calculate in each case the mixture of metasilicates. His analyses indicate that Tschermak's theory of the relation between Al_2O_3 and the oxides of Ca, Mg, and Fe holds good in the case of only about one-half of the New York pyroxenes analyzed. Not the least valuable portion of the paper is a list of the literature bearing on the subject and including some sixty papers. H. F. B.

Fifteenth Annual Report of the United States Geological Survey, 1893–4.

The administrative portion of the report is followed by five papers of considerable importance. The first is a preliminary report upon the Geology of the Common Roads of the United States, by N. S. Shaler, and includes an outline of the history of American road building, with studies on the value and distribution of road stones, the methods of their use, the effects of geologic structure on the grade of roads, the value of block paving and paving brick and the action of rain and frost upon roads and road material. The paper is a timely contribution to a subject of increasing interest.

The second paper is by L. F. Ward and is upon the Potomac formation. It is the result of detailed studies upon the flora and the stratigraphy of the formation. It is notable in that Mr. Ward divides the formation into six separate series of beds to which local names are given.

A. C. Lawson contributes a sketch of the Geology of the San

Francisco Peninsula, which includes studies of the Franciscan series, the Serpentine, the Tejon sandstone, the Merced series, the Terrace formations and the diastrophic record.

The Marquette iron-bearing district of Michigan is treated in a preliminary report by Van Hise and Bayley, with a chapter upon the Republic trough by H. L. Smyth. The Basement Complex, the Lower Marquette and the Clarksburg formations are treated with considerable detail.

The Origin and Relations of the Central Maryland Granites is treated by C. R. Keyes after an important introductory chapter upon the General Relations of the Granite Rocks in the Middle Atlantic Piedmont Plateau, by the late Professor G. H. Williams.

H. F. B.

Notes Concerning a Peculiarly Marked Sedimentary Rock. By Dr. J. E. Talmage, President and Deseret Professor of Geology, University of Utah. Published in pamphlet form, with five plates, reprinted from the *Utah University Quarterly.*

The author describes and illustrates a fine-grained argillaceous sandstone, bearing peculiar surface markings consisting mostly of straight lines intersecting at right angles with almost mathematical precision. The deposit was examined by the writer in place, and an extensive collection of specimens was made under his direction by the "Utah University and Deseret Museum Expedition of 1895." The formation consists of undisturbed sedimentary deposit, referred to Trias or Jura-Trias age, and occupies a relatively low table land between the Kaiparowitz and the Paria plateaus on the north of the Colorado River near Glen Canyon, Arizona. The bed of marked rock is almost two feet thick, and lies conformably between deposits of coarser sandstone, which show none of the rectilinear markings. While the most regular arrangement of the marks appears on slabs with perfectly flat surfaces, yet the rectilinear intersections are plainly shown on warped and ripple-marked surfaces. The lines are so regular as to suggest the possibility of human instrumentality when hand specimens only are examined. The author has performed a number of experiments to test the theory of sun-crack or shrinkage-fissure origin, with negative results; but succeeded in producing marks similar in appearance through the formation of ice-crystals on mud formed from the pulverized stone. Then by pouring on such mud concentrated natural brine from the

Salt Lake, crystals of mirabilite and others of common salt were formed, and these impressed the mud, producing straight lines though without rectilinear intersections. The writer says with reference to this last experiment:

"One would hardly hold, even as a working hypothesis, that lines of 200 or 500 cm. could be produced in any such way; though the supposition may be ventured that under particularly favorable conditions a thin crystalline cake might form on shore sediments, and this by a cleavage of its own might become fissured in an orderly way, the cracks extending to the mud surface beneath, and marking the same superficially; or if the under stratum had a very thin top layer of fine-grained material the depressions might extend through the same. A fresh addition of sediment would fill the cracks and perpetuate the mud marks, while the deposit of soluble mineral might be removed by solution. Shallow line-like depressions in the mud might possibly determine the position of incipient cracks in a subsequent process of slow shrinkage. However, such suppositions lack a stable experimental foundation."

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DRAINAGE MODIFICATIONS AND THEIR INTERPRETATION.[1]

PART II. CRITERIA FOR DETERMINING STREAM MODIFICATIONS.

(1) ALIGNMENT OF THE DRAINAGE AFFECTED BY THE MIGRATION OF DIVIDES.

BEFORE attempting to apply the law of the migration of divides, it is well perhaps to consider how its operation affects the arrangement of the minor drainage lines; and thus become better acquainted with the criteria of change which we may expect to find in the field.

(*a*) *Rectangular arrangement of the drainage lines.*— Here again we must begin with the simplest conditions possible and progress to the more complex. Manifestly the simplest condition we can assume is that of a region so long subjected to base leveling processes that its surface is a plain with but slight irregularities, standing at or near sea level. The strata must be practically homogeneous and horizontal. The first of these conditions insures an equilibrium of the streams,—a perfect inter-adjustment of the branches which is impossible under other than base-leveling conditions. The second eliminates the effect of geologic structures and the varied character of the rocks which almost always exerts an important influence. When the external influence of geologic structure and character of rocks is removed

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from the question the law of migration of divides will cause modifications in all the streams within the area affected by the uplift or depression. This applies to streams belonging to the same system, as well as those belonging to different systems. and operates as follows: Wherever two streams are contesting for a divide, and the surface is tilted in a direction perpendicular to that divide, the streams located on the side of the greatest tilting will rob their adversaries of the contested ground and the divide will migrate indefinitely, depending upon the amount and continuation of the movement and the size of the opposing streams. Under such conditions the smaller streams will extend their head branches directly toward the line of greatest uplift, and consequently will arrange themselves at right angles to, and flow away from the axis of uplift, or toward the axis of depression. The larger streams which cross the axis, will be variously affected by the movement, depending upon the volume of the stream and the rate of the uplift. If the volume of water is great and the uplift sufficiently slow, the river may corrade its channel as fast as it is elevated, and so maintain its position. If the rate of uplift is more rapid than that of corrasion, the stream will become ponded and probably robbed of a large portion of its drainage basin by a more favorably located rival.

The small branches, having assumed a course at right angles to the axis, will carry their waters away from the axis until they pass beyond the region affected by the tilt, or join some longitudinal stream of sufficient size to have maintained its course despite the uplift.

The major streams tend to arrange themselves parallel with the axial line, hence they will flow approximately at right angles to the minor drainage lines, producing a rectangular system. A large stream flowing originally parallel with the axis will tend to retain this parallelism, unless it is tapped by some lower stream, and in that event the chances are that it will be tapped by a stream flowing perpendicular to the axis, and the major stream will be transferred to a lower course. In no case, unless local obstacles interfere, will the stream pursue a diagonal

course; its constant tendency is toward courses at right angles to, or parallel with the axis. If the movement is enough to give the rocks an appreciable dip, the stream, in corrading its channel, will tend to cut its banks on the lower side, and in doing so will migrate down the slope of the beds, but in all such cases the stream will move as a whole, still retaining its parallelism with the axial line. If the stream flows, in general, parallel with the axis, but in a broadly meandering course, the tilting will give to the stream a tendency to cut off its ox-bows and so straighten its course and at the same time migrate away from the axial line. This change is produced by the retardation of the current in that portion of the bend in which the stream flows toward the axis, and an acceleration in that portion in which the stream flows away from the axis. Figure 9 represents such a stream on a

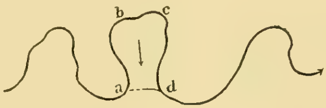

FIG. 9.

surface tilted in the direction of the arrow. In the course *a b* the grade is lessened by the tilting and consequently but little corrasion is accomplished but in the course *c d* the grade is steepened and corrasion is greatly stimulated. As a result of this change in the grade of the stream, the channel at *d* is very much lower than at *a*, hence a small stream may easily work back across the neck of the bend and capture the main stream at the point *a*. This process tends to straighten the course of the stream and at the same time causes it to migrate away from the axial line.

Again the original course of a stream may be neither parallel with, nor perpendicular to the axial line, but may pursue a diagonal course indicated by *A B* in Fig. 10. If such a stream has a branch (*A C*) which flows parallel with the axis, under certain conditions a small branch (*a b*) of the lower stream may cut through the divide separating the two streams and rob the diagonal stream of its upper portion. Ordinarily such a transfer

would probably not take place, for the stream *A B* would probably corrade its channel about as rapidly as the land rose, and so would prevent the lower stream from affecting its capture.

If, however, the arrangement shown in Fig. 10 prevails at the close of a period of quiescence in which the surface is worn down close to baselevel, the streams would be in a position to

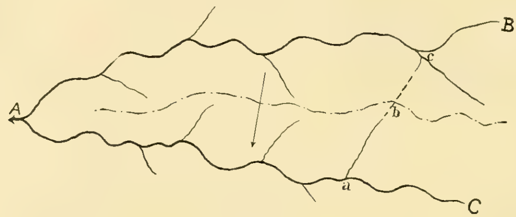

Fig. 10.

take advantage of any opportunity to extend their drainage basins. If at such a time a tilt occurred in the direction indicated by the arrow the point *a* on the stream *A C* would remain at about the same elevation as *A*. The stream *A B* would be accelerated, but active corrasion would, for a long time, be mainly limited to its lower course. The branch *a b* would be greatly accelerated and might be able to cut headwards to the point *c* and capture *c B* before *A B* cuts back to the point *c*. Whether this diversion would be accomplished or not, depends upon the rapidity of the uplift, the volume of water in *A B*, and the character and attitude of the rocks between the two streams.

Thus the migration of divides on a tilted surface tends to produce a system of drainage, the small branches of which are perpendicular to the axial line, and flow in the direction of the dip of the surface; and also a series of branches of the second order, flowing parallel with the axis, and in general coinciding with the downward pitch of the same. When the axis of uplift coincides with a divide already established, it is obvious that the divide will be preserved, but a rearrangement will take place in the head branches of the contending streams. The increased gradient will induce the small branches to extend their upper courses directly toward the axis, and the larger streams will

adjust themselves in a direction perpendicular to the course of the small streams; so the final result will be an arrangement of the drainage similar to that which occurs when the uplift is in any other position.

(*b*) *Unsymmetrical drainage basins.* — When the tilting affects a territory broad enough to include several systems of greater or less extent, a peculiar arrangement is produced which can be

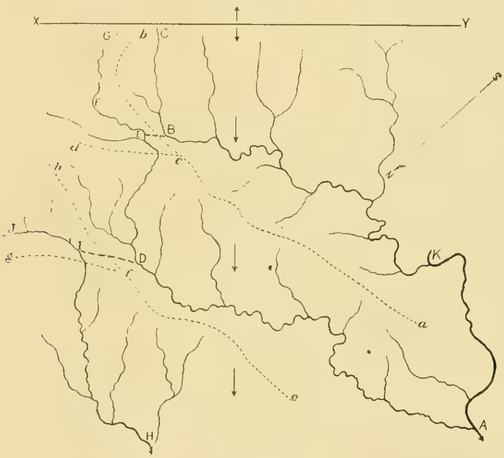

FIG. 11.

easily recognized, and which shows at a glance the direction of the tilt which produced it. The minor drainage lines, as just described, will arrange themselves in general lines at right angles to the axis of uplift, and will unite in trunk streams parallel to the rising fold. Figure 11 represents the drainage on such a broadly tilted surface. The axis is indicated by the line *X Y*. The territory is divided among the streams *A B C*, *A D G*, and *H I J*. It is but reasonable to suppose that before the tilting occurred, these streams were in about the center of their respective basins. As the land rose along the line *X Y* the minor branches on the right-hand side of the larger streams were retarded by the uplift, whereas the branches on the left were accelerated. These accelerated streams crowded the divides farther and farther up the slope and at the same time extended

their head branches directly toward the axis. This produced very unsymmetrical basins in which the trunk streams are flowing on the lower side of the basins, with the minor branches reaching toward the stream next above.

Sometimes these long aggressive tributaries work through the divide and tap the headwaters of the stream next above. In Fig. 11 there are two such cases of robbing; one at the point *E* where the branch *D E* has apparently cut through the divide *c d* and beheaded the stream *A B F G*, and the other at the point *I* where *H I* has robbed *A D I J* of the portion *I J*.

(2) EFFECT OF THE EARTH'S ROTATION ON DRAINAGE LINES.

Kerr[1] observed such an arrangement of the streams of eastern North Carolina, but he attributed their origin to an entirely different cause, viz., the rotation of the earth on its axis. In arriving at this conclusion, he considered the possibility of a tilted surface, but dismissed the idea as untenable. In support of the former hypothesis he cited a few isolated cases which seem to favor his view of the case.

Gilbert,[2] in his study of the effect of rotation, reached the conclusion that the cause is adequate, under favorable conditions, to produce such results, and referred to the drainage of the southern side of Long Island as an illustration of the working of the law.

It is not the purpose of the writer to enter into a discussion of the efficiency of the rotation of the earth in producing drainage modifications of a certain type; but rather to show that such peculiarities are of very common occurrence in places where rotation could hardly have been an active agent, and that some other cause is capable of producing the same effect. As will be pointed out later, changes of just such a character as those described by Kerr in North Carolina and by Gilbert in Long Island can be found in almost every stream of the Appalachian

[1] Geology of North Carolina, 1875, by W. C. KERR, pp. 9–12.

[2] The Sufficiency of Terrestrial Rotation for the Deflection of Streams. Am. Jour. Sci., Vol. XXVII, pp. 427–432.

region. These streams instead of showing the regularity in direction which would be expected if the cause is the rotation of the earth, exhibit an irregular arrangement which clearly indicates that the cause is local and not general. As will be shown later these modifications have a certain definite relation to the great uplift along the Appalachians and seem without much doubt to owe their origin to the tilting which accompanied this uplift. The writer would also suggest that even in the coastal regions there may yet be found evidence of decided elevation, or tilting, of which the visible coastal sediments give no indications.

We have then two theories to account for this class of facts: terrestrial rotation, and the natural adjustment of the drainage upon a tilted surface caused by crustal movements. It has been demonstrated in the previous part of this paper that the latter theory is entirely adequate to produce the given effect, and also that these earth movements have been of frequent occurrence in the past. On the other hand, the sufficiency of the former hypothesis is a matter of doubt, even in the minds of the eminent scientists who have investigated it.

When the practical application of the law of the migration of divides is made, the question becomes very complex. Alternating hard and soft beds, even when they are approximately horizontal, tend to modify the result; but they are infinitely more potent in shaping the lines of drainage, when they are tilted at various angles, or bent into great folds. At first sight it would seem impossible in such regions to detect any change due to slight surface warpings, but careful study reveals the fact that even here the streams are affected by it, showing by their arrangement the position of the axis of movement and something of the relative steepness of the slopes.

(3) MODIFICATIONS DIFFER ACCORDING TO AGE.

(*a*) *Recent movements shown by barriers and changes of grade.* — The most recent uplifts have not yet affected the alignment of

the streams, for that is a matter of slow development. If the uplift rises athwart the stream, the first recognizable feature is the change of grade in the river profile and the formation of a barrier at the point where the axis crosses the stream. If the stream is flowing over soft, homogeneous rocks, corrasion may take place so rapidly that no appreciable barrier is produced, but as a rule we may expect to find some feature characteristic of a revived stream at this point and ponding in the stream above the barrier.

(*b*) *Remote movements shown by the arrangement of the minor drainage.* — Movements which occurred in the remote past have left no record where they crossed large streams, unless the movement was so severe as to cause reversal but the minor drainage lines may be marked by all of the characteristics described in this paper. The divides may have migrated until all of the stream basins are unsymmetrical, having the main stream near one side and the minor drainage lines reaching out toward the axis of uplift. Unless counteracted by geologic structure, the rectangular arrangement of the drainage lines will be permanent, so long as the crustal movement continues, or until counteracted and obliterated by reverse movements. In such cases if the change has not progressed too far it is generally possible to find cases of stream capture and other marks of radical rearrangement.

(*c*) *Very remote movements shown by the arrangement of the trunk streams.* — As we go farther and farther back into the past, the evidence becomes less and less perfect, until at last it is only in the arrangement of the great streams that we can find a trace of the conditions then prevailing. This of course is unsatisfactory, since it is bare of all details, but in a broad way it outlines the movements which shape the main drainage-ways of that distant age.

(4) PERIODICITY OF STREAM CHANGES.

There is another point which it is well to consider in the application of the law of the migration of divides, and that is,

that the changes induced in the drainage systems are inclined to be periodic in their occurrence. This is extremely important, since it enables us to locate in time many of the changes which otherwise we would be unable to fix definitely.

Streams are so susceptible to prevailing conditions that they do not always respond to the tilting of the surface. There are times when a tilt produces but little effect; then again a slight movement will produce the most profound modifications. If the tilting occurs while the streams are in their youth, it will have but little effect upon them unless it is excessive. In that period of its existence the stream is active, it is cutting its channel vertically, and it is well entrenched in its position, hence a slight tilt of the surface will produce no appreciable effect. If the streams are in their old age, the surface of the land will constitute a peneplain, and if in extreme old age, this peneplain will approach very closely to baselevel. At such times the drainage basins are delicately balanced against each other; not alone are the systems so balanced, but each individual stream is pitted against its neighbors in a balance so delicate that the least outside influence may turn the scale, and the favored stream conquer the ground now occupied by its neighbors. It is at such times that crustal movements are accompanied by the most profound results; consequently we find that a large majority of the changes in the alignment of the drainage systems of the Appalachian region have occurred after a period of extensive baseleveling; they were caused by the first movement which terminated the quiet of the long period of uninterrupted erosion.

(5) CRITERIA FOR DETERMINING THE COINCIDENCE OF LINES OF UPLIFT WITH PREËXISTING DIVIDES.

Since, under favorable conditions, the final result of all long-continued local uplifts has been the migration of the divides to the axial line of the uplift, it would seem difficult, if not impossible, to establish criteria by which to separate the uplifts which originally coincided with divides, from those which were differently located. In a measure this is true, but there are certain

characteristics which seem to mark such uplifts and separate them from the general class.

If a drainage basin, having a long circuitous outlet to the sea, or one which is greatly retarded in its development by hard rocks, maintains its balance against an opposing stream having ready access to the sea, it is altogether probable that this balance has been maintained by an uplift which corresponded originally with the divide between the basins.

PART III. APPALACHIAN DRAINAGE.

The preceding portion of this paper has been devoted to the demonstration of the law of the migration of divides, and in presenting the criteria by which such changes in the drainage systems may be recognized. These criteria are divisible into three classes, indicative of different degrees of change, as follows:

Class 1.—Barriers or obstructions in the channel of a large stream with attendant features which are indicative of very recent movement,—so recent indeed as to have no effect upon the alignment of the stream or any of its branches.

Class 2.—Complete rearrangement of the minor drainage lines. This points to a pronounced warping at a time so remote that all of the lesser streams have become adjusted to it by changing their courses as previously described.

Class 3.—Certain arrangement of the trunk streams, indicative of crustal movements of pronounced character and of very ancient date.

It now remains to examine hastily some of the drainage systems of the United States, to see if we can detect any of these characteristics. In so doing, attention will be confined almost exclusively to the region east of the Mississippi River, as being the one with which the writer is most familiar; and in this Appalachian region we shall consider only that portion which is south of the great terminal moraine, for in glaciated regions the problem of stream modifications is entirely too complex for present consideration.

(1) RECENT MOVEMENTS INDICATED BY THE MUSCLE SHOALS IN THE TENNESSEE RIVER.

The Tennessee River is obstructed, in its course through northern Alabama, by a barrier which is widely known as the Muscle Shoals, and which has been, until the completion of the canal in recent years, a serious bar to the navigation of the stream. In this case there is no possibility of the existence of an old, abandoned channel around the obstruction, such as characterizes the falls of the Ohio River at Louisville, Kentucky. The Tennessee River at the Muscle Shoals is occupying the same channel that it did in late Tertiary time, hence the obstruction in the stream must be accounted for by some hypothesis which admits of the occupancy of the present channel for an indefinitely long time.

Such a barrier can be produced in one of two ways: either the entire region has suffered an uplift and the river has only succeeded in cutting its channel back to Florence, Alabama, or a local uplift has occurred at this point which has elevated a small portion of the stream above its normal grade, and this uplift has been so recent that the stream has not yet been able to remove the barrier. In order to determine which hypothesis best accounts for the facts, it will be necessary to examine closely all of the characteristics of the stream both above and below the barrier.

(*a*) *Profile of the Tennessee River.*—From Chattanooga, Tenne-essee, to Brown's Ferry, Alabama, a few miles below Decatur, there is a fall of but 49 feet in 185 miles; below Brown's Ferry for a distance of 57 miles the descent is rapid, amounting to a total of 169 feet; below this the grade is again slight, having a fall of only 120 feet in 250 miles.

From these figures it is apparent that there is not only a break in the grade, but also that the elevation of the head of the shoals is above the average grade of the river from Chattanooga to its mouth. This evidence appears to favor local uplift, but it is not conclusive.

(*b*) *Character of the river valley.*—From South Pittsburgh, Tennessee to the head of the shoals, the valley of the Tennessee River is broad and worn down about to the baselevel of the stream at the head of the shoals. Reliable data concerning the character of the valley below the shoals are difficult to obtain, but the preponderance of evidence seems to show that this also is a rather old valley, with all of the side branches cut down to the level of the river. From this it appears that the valley below the shoals is fairly comparable in age and amount of excavation to the valley above the shoals, and that both have the appearance of considerable age. Between these two old portions of the valley lie the Muscle Shoals in which active corrasion is going on today. This result could not have been produced if the region had suffered general elevation alone; hence the question is narrowed down to the theory of a local uplift.

(*c*) *Character of the stream.*—Since the rocks composing the shoals are the hard, cherty beds of the lower Carboniferous, we should expect to find some evidence of ponding above the shoals, if they were caused by a local uplift. According to the Huntsville sheet of the United States Geological Survey and the description given by the Army Engineers[1] who made the survey of the river there are distinct traces of ponding from Brown's Ferry to a point south of Huntsville. All of the phenomena associated with the Muscle Shoals point to a recent and local uplift as the cause of the barrier.

There are many other streams in the Appalachian region which show barriers and gorges of quite recent construction, but in most cases they are due to a general elevation which has simply produced a revival of the stream. A critical study of these obstructions fails to reveal the characteristic features found in the Tennessee River at the Muscle Shoals.

(2) REMOTE CHANGES SHOWN IN THE STREAMS OF THE MISSISSIPPI VALLEY.

The adjustments of this order are confined to the rearrange-

[1] Report of the Secretary of War, Vol. II, 1868–69, p. 584.

ment of the minor drainage lines, hence a study of these will be best facilitated by an accurate drainage map.

Numerous cases of such adjustments can be found in the streams of the Mississippi Valley, where the general horizontality of the rocks keeps the problem free from great complications. In this region we find many cases of the migration of divides and the complete rearrangement of the drainage lines.

(*a*) *Kanawha River basin.*—A noteworthy case of this kind, occurring in the central portion of West Virginia, is shown in Fig. 11, and has been described in the previous portion of this paper as a type example of its kind. *A K* (Fig. 11) is the Kanawha River, *K B C* is the Gauley River, *A D G* is the Elk River, and *H I J* is the Little Kanawha River. The first two streams belong to the Great Kanawha system and the last to the Little Kanawha or Ohio River system. As previously explained, the divides have migrated toward the southeast, until in places they are within a mile of the stream next above. It will be noticed that this action is much more effective near the heads of the streams, for at this point alone has capture resulted. Lower down, the divide still remains close to the stream above, but diverges more and more until, as it approaches the mouths of the streams, it is about equally distant from the stream above and the stream below. This is doubtless due to the fact that most of the shifting occurred when the region was uplifted and tilted, after the cutting of the extensive peneplain which is a marked feature of the region. The large volume of water in the lower courses of these streams enabled them to maintain their former courses and quickly intrench themselves within the tilted plain. Since then their cutting has been so rapid that it has overbalanced all of the effects of the tilt; consequently their basins, in this portion of their courses, are approximately symmetrical. Farther up the streams, where the volume of water was less, the streams were unable to so fortify themselves, and consequently were dispossessed of most of their territory by their lower neighbors. At their extreme heads, the streams were held for a long time on the surface of the peneplain, and

the tilting exerted its full force in producing a rearrangement of the drainage lines. The result of this exposed condition is that most of the streams have been captured by branches working back from the northwest producing the imbricated arrangement shown in Fig. 11.

In the light of the previous discussion, there seems to be no question that this condition is due to a gentle tilting of the surface toward the northwest from near the Greenbrier River. In this region the inter-stream areas are of such an elevation that the principal migration must have occurred long ago—when the general surface was many hundreds of feet higher than today, and at a time when the surface relief was slight. There were probably two periods when such a change could have taken place, contemporaneously with the completion of either the Cretaceous or the Tertiary peneplains. The character of the changes point rather to the latter than to the former; for if the tilting had occurred in Cretaceous time, subsequent changes would, in all probability, have obliterated the courses of the minor streams. But it is the minor drainage lines which are here the characteristic features and which were probably formed long after the uplifting of the Cretaceous plan from baselevel.

(*b*) *Big Sandy and Clinch River basins.*—Southwest of New River, the streams flowing directly to the Ohio are encroaching upon the streams of the Tennessee system, although the latter has a decided advantage in the soft limestones and shales of the Appalachian Valley. Tug fork of Big Sandy River has cut entirely across the coal field, and its head is within a mile of Clinch River at a point fifteen miles below the source of the latter.[1] Not only has it encroached to within such a short distance, but it is flowing more than 300 feet below Clinch River at the point of its nearest approach. In its backward cutting it has reached the Valley limestone and, if conditions remain unchanged, it will be but a short time, geologically speaking, until it will capture Clinch River at this point. The migration of this divide is in the same direction as the cases already cited and is evi-

[1] See the TAZEWELL Atlas sheet of the U. S. Geological Survey.

dently the result of the same cause. This is doubtless the uplift already described by C. W. Hayes and myself;[1] an uplift which accelerated the northwestward flowing streams, but retarded Clinch River by crossing that stream some distance below its source.

(*c*) *River basins of Kentucky.*—The state of Kentucky, lying almost entirely within the undisturbed region of the Mississippi Valley, presents a fine field for the study of drainage forms. A glance at the map of the state shows that even in that region of nearly horizontal rocks the drainage is not well balanced, the stream basins are not symmetrical, and the divides are apparently migrating. Shaler recognized these peculiarities, but he was unable to offer an adequate explanation. He writes as follows:[2] "It is not easy to account for this irregularity in the disposition of the streams away from the mountain regions. Away from those disturbed regions there are only slight irregularities in the rocks, which do not seem to have any power of determining the range of a river basin." He then suggests that their peculiarities may be inherited from conditions in previous ages, when the distribution of hard and soft rocks was very different from that which prevails today.

In the light of the present study, the arrangement of the drainage lines of Kentucky is not peculiar; in fact much of it is most natural and what we would expect, if the surface slopes from the interior toward the Ohio River. The divide on the north side of Cumberland River is apparently encroaching on that stream under an influence similar to that which permits Big Sandy River to encroach upon Clinch River. This encroachment is so pronounced that at one time it was proposed to divert the waters of the upper Cumberland into Goose Creek, a branch of the Kentucky River. The headwaters of Green River also are crowding back toward the southeast against the Cumberland basin and have now approached to within a very few miles of the main river. These divides must have migrated toward the

[1] Geomorphology of the Southern Appalachians, Nat. Geog. Mag., Vol. VI, p. 94.

[2] Kentucky Geological Survey, Vol. III, New Series, p. 360.

latter stream, hence we conclude that the prevailing tilt of the surface has been toward the northwest and away from the Cumberland River.

Some of the peculiarities cannot now be satisfactorily explained even on this basis, but the writer believes that it is because of the lack of reliable data and of the complexity of the problem. They are doubtless due to the same cause, but in all probability it has not always acted in the same place, nor in the same direction.

(3) REMOTE CHANGES SHOWN IN THE STREAMS OF THE ATLANTIC SLOPE.

Throughout the gulf coast of the Atlantic slope there are numerous examples of migration of divides and the consequent unsymmetrical condition of the stream basins. The limits of this paper will not permit of a full discussion, so only a few can be mentioned.

(*a*) *Chattahoochee River.*—The most pronounced case of the kind is the encroachment of the Atlantic streams upon the Chattahoochee River. From Columbus, Georgia, to its headwaters, the drainage basin of this river is limited almost entirely to its northwestern side. Figure 12 shows the arrangement of the drainage lines in the region about the headwaters of the Chattahoochee River. *A B* is the Etowah River; *C D*, the Chattahoochee River; *G*, the Oconee River; *H*, the Broad River; and *K L*, the Savannah River. The Atlantic streams, or those flowing toward the southeast, have symmetrical basins in which are developed beautiful dendritic drainage lines. The small branches are numerous and have straight, regular courses at right angles to the main line of the Chattahoochee River This arrangement of the minor drainage lines is indicative of a strong southeastward slope of the surface. These minor streams have not only arranged themselves parallel with the line of greatest slope, but they have also extended their courses headwards, until at one point they are within a mile of the Chattahoochee River and at least 100 feet below it.

At this point, which is in the vicinity of Gainsville, Georgia, the capture of the Chattahoochee is imminent, and if conditions remain unchanged, will doubtless be accomplished in the near geologic future. In the vicinity of Tallulah Falls the same process has been carried on, but in this case it has reached completion, and the Savannah River has cut through the divide and

FIG. 12.

captured the portion *L M*, which formerly constituted the headwaters of the Chattahoochee.

The minor drainage lines in the Chattahoochee basin have also arranged themselves parallel with the line of greatest slope of the surface. They, in turn, are encroaching upon the drainage basins to the northwest, although their headward progress is greatly retarded by the mountainous character of the divide upon which they are encroaching. At the point *E*, however, a small branch of the Chattahoochee has already succeeded in capturing the stream *E F*, which doubtless previously belonged to the Etowah River.

This example is somewhat complicated by complex geologic structure, but the arrangement of the minor streams across this structure appears to be evidence of even a more pronounced tilting of the surface than that which has caused such a radical

rearrangement of the drainage in West Virginia. The fact that the extreme head branches of the Atlantic streams have been enabled to cut below the bed of the Chattahoochee seems also to show that these streams have had a decided advantage since the elevation of the Tertiary peneplain to its present altitude.

(4) REMOTE CHANGES SHOWN IN THE STREAMS OF THE APPALACHIAN VALLEY.

So far we have considered only those cases in which geologic structure has played little or no part in shaping the courses of the streams. While in such cases the effect of surface tilting is most pronounced, it has also operated in the Appalachian Valley where geologic structure dominates the whole topography.

No one can consider for a moment the drainage basins of the Susquehanna, Potomac, James, and Roanoke rivers without being impressed by their unsymmetrical condition. In the case of the Roanoke and New rivers, there can be no doubt that the former is encroaching upon the grounds of the latter. This is so apparent that a traveler on the railway easily distinguishes the difference in grade on the two sides of the waterparting between them. In this case, although the divide may now be migrating toward New River, it is very certain that this has not continued for a long time, else New River would have been captured long ago. Here we are not concerned about the migration of the divide, but rather about its non-migration. Since for a long time, New River must have been working at a great disadvantage against Roanoke River, why has not the latter cut through the divide at Christiansburg and captured the entire head of the former stream?

As has been explained, the preservation of a divide under unfavorable circumstances is no more anomalous than the migration of a divide toward the axis of uplift; it simply indicates that the unfavorably located stream has been assisted in the preservation of its drainage basin by an uplift which corresponded with the preëxisting divide between the contending streams; and which by its continued movement has prevented the aggressive stream from absorbing its weaker neighbor.

The constantly increasing magnitude of the river basins in the Appalachian Valley from New River to the Susquehanna, at once suggests the idea that the northern streams have been more favored in their development than the southern streams, and as a result have grown largely at the expense of the latter. Roanoke River has but a few square miles of its basin within the rocky walls of the Blue Ridge; James River has pushed farther toward the northwest, but is still confined well within the limits of the zone of folded rocks; Potomac River controls much more of the area in question and is practically limited in its northwestern side by the Alleghany front; Susquehanna River has not only gained control of a large portion of the valley, but has also extended its headwaters far back into the Alleghany plateau of western Pennsylvania and southern New York. It is at once obvious that these streams are working under different conditions; and judging from their arrangement, it is probable that much, if not all, of this difference is due to difference in amount of interior uplift, and also to the location of the axis of the movement.

The water parting between the Atlantic streams and those belonging to the Ohio River drainage basin forms a remarkably regular line which crosses the valley obliquely from the Blue Ridge south of Roanoke, Virginia, to McKean county, Pennsylvania. From the criteria already established this would appear to mark the position of an axis of uplift which has been mainly instrumental in shaping the drainage basins on either side.

From the James to the Susquehanna the basins are decidedly unsymmetrical; the divides have migrated toward the southwest, until the divide between the Susquehanna and the Potomac approaches close to the left bank of the latter stream, and the divide between the Potomac and the James allows to the former about twice as great an area as it does to the latter. This migration is certainly due to a tilting of the surface toward the northeast, which favored the development of the Susquehanna at the expense of the Potomac, the Potomac at the expense of the James, and the James at the expense of the Roanoke River.

Examples may be multiplied indefinitely, but enough has been cited to show that Appalachian drainage has all of the marks which theoretically we should expect to find on a tilted surface.

(5) VERY REMOTE CHANGES SHOWN IN SOME OF THE APPALACHIAN RIVERS.

In passing still farther backward in geologic time, the minor drainage ceases to be our guide; and we are limited to the big trunk streams from which to read the history of events. Almost every large stream of the Appalachians gives some hint of the surface conditions under which it was formed.

(*a*) *Chattahoochee drainage line.*—The limits of this paper will not permit the mention of all the probable examples, only a few of the most striking will be given. Perhaps the most pronounced example of the kind, and at the same time one that carries the history back the farthest, is that of a series of streams on the eastern side of the Blue Ridge, the arrangement of which appears to have been determined by the depression which preceded and made possible the deposition of the Triassic sediments of the eastern part of the United States. A glance at a map reveals the fact that the course of the Chattahoochee River above Columbus, Georgia; the Savannah above Tallulah Falls; the French Broad above Asheville; and the upper portions of the Catawba and Yadkin rivers occupy almost continuously a line from the margin of the Cretaceous sediments of the Gulf coast to the Triassic deposits of the Dan River area. This continuity of drainage lines at once suggests some common cause, for it seems highly improbable that their location along this line was simply fortuitous. According to the principles laid down in the preceding parts of this paper, such an arrangement could have been brought about by a subsidence the axis of which corresponds with the present drainage lines.

(*b*) *Triassic areas in the same line.*—The areas of Triassic rocks in this region are generally regarded as remnants of a more extended deposit which took place in troughs formed by

local subsidences. The remaining areas of these rocks seem to range themselves in two approximately parallel lines. The westernmost line consists of the Dan River[1] and Danville areas, Scottsville and Barboursville areas, and the great New York-Virginia area stretching in an almost continuous line from Germantown, North Carolina to Stony Point, New York. This is the direct continuation of the Chattahoochee drainage line, and, strangely enough, it is apparently continued to the northward by the valley of the Hudson River and Lake Champlain. The easternmost line, consisting of the Wadesboro and Deep River areas, the Richmond area and the Connecticut area, roughly parallels the first, and it has a northward extension in the Connecticut River Valley. Whether or not it ever had a southwestward extension similar to the parallel line cannot now be determined, for post-Triassic erosion and sedimentation have removed all traces of such streams if they ever existed.

These parallel lines are everywhere marked by stream valleys or areas of deposition, therefore by our criteria they should mark the axes of parallel depressions. These depressions seem to have reached their maximum near the center of the line, for in this portion the sediments probably formed a continuous sheet, indicating that the old land surface had sunk entirely below water level. This maximum submergence appears to have been along a cross axis, or one extending in a northwest and southeast direction; and to this cross depression is probably due the location of the Susquehanna River, the largest and most vigorous of the central Atlantic streams. Judging from the direction of the flow of the streams located along the longitudinal axis, it seems probable that the depression reached a minimum at the southern line of North Carolina, for at that point the waters divide toward the southwest and the northeast.

If our interpretation is correct, these are some of the oldest streams in the United States. With the one exception of the upper portion of Savannah River, which formerly belonged to the

[1] The names of the various areas of Triassic rocks are taken from Correlation Papers — The Newark System, by I. C. Russell, Bulletin No. 85, United States Geological Survey.

Chattahoochee system, it seems probable that they have persisted in the course then determined up to the present time. This interpretation also presupposes the existence of a peneplain at the time the depression occurred, for with the present rugged topography along this line almost no amount of tilting could produce such a radical rearrangement of large streams as that which inaugurated Triassic deposition. This conclusion is perhaps the most important result of the present study, for it appears to verify the statement of Davis[1] that the Atlantic slope was reduced to a peneplain before the deposition of the Triassic sediments. In order to permit the formation of such longitudinal streams, the peneplain must have been practically continuous along the axis of the western fold, and hence today must be at an altitude at least equal to that of the main summits which cross the line.

(6) UTILITY OF THE STUDY OF DRAINAGE FEATURES.

It now remains but to add a word concerning the utility of this study. If the writer has succeeded in establishing the proposition that streams suffer modifications during crustal movements, no one can deny that a careful study of such modifications is extremely important in determining the principal movements in recent geologic ages. If it will do that, it is practically as efficient as the study of physiographic forms. The writer does not wish to be understood as advocating the replacement of the study of physiographic forms by the study of drainage forms, but rather to use the two in conjunction; in other words, to study the forms assumed by the instruments of erosion at the same time that we are studying the land forms produced by these same instruments—the streams. The results cannot be at variance and the studies will be a mutual advantage, one to the other.

MARIUS R. CAMPBELL.

UNITED STATES GEOLOGICAL SURVEY.

[1] The Geological Dates of Origin of Certain Topographic Forms on the Atlantic Slope of the United States, by W. M. Davis, Bulletin Geological Soc. Am., Vol. II. p. 549.

ON THE MONCHIQUITES OR ANALCITE GROUP OF IGNEOUS ROCKS.

As is well known to all petrographers the name of monchiquite was first given by Rosenbusch[1] in 1890 to a series of dark basic dikes occurring in connection with intrusions of eleolite-syenite in Brazil. Similar rocks had been previously known from South Portugal and hence they received their name from the Serra de Monchique.

The material from Brazil was investigated by Hunter and Rosenbusch, and the rocks which have a basaltic habit were found by them to consist of ferro-magnesian minerals in a glass base. The ferro-magnesian minerals were found to be always olivine and pyroxene, while with them were associated sometimes amphibole, sometimes biotite, and sometimes both, and according to these variations the group was subdivided.

Since then these rocks, of slightly varying types, have been found, usually in connection with intrusions of alkali syenites, in various parts of the world. In this country they have been found in Arkansas and in numbers in the Lake Champlain district, and our knowledge of them is chiefly due to the researches of Kemp.[2]

In all cases the main characteristics of the types described are that the rocks consist of ferro-magnesian minerals, chiefly olivine and pyroxene, lying in what is called a colorless glass base.

The only case in which, so far as we know, this colorless base has been investigated was in the original study by Rosenbusch and Hunter, in which it was separated and analyzed and

[1] Tscher. Min. Mitt., Vol. XI, 1890, p. 445.

[2] Trap Dikes, Lake Champlain Region; Bull. 107, U. S. G. S., 1893. Igneous Rocks of Arkansas; Ann. Rep. 1890, Vol. II, p. 392 (with J. F. Williams).

found to consist chiefly of silica, alumina, soda and water. Thus, as Rosenbusch pointed out, it had certain analogies with an eleolite-syenite magma from which the partial magma forming the dikes is supposed to be formed by differentiation of the lime, iron and magnesia. On account of the water it is called a pitchstone glass.

Within the past few years the attention of the author has also been directed to this group of rocks by their occurrence in parts of Montana now being studied in conjunction with Mr. W. H. Weed, under the auspices of the United States Geological Survey. When they first appeared the characterization of them as consisting of ferro-magnesian minerals in a glass base, given by previous authors, was accepted, and one of them so described (in the report on the geology of the Castle Mountain mining district, now passing through the press).

As, however, the number of examples increased and the rocks were studied in connection with their geologic mode of occurrence, it became a source of perplexity as to why such basic magmas, solidifying under the conditions which the general geology of the region evinces, should have formed so much glass.

For it must be said that *a priori* one would scarcely expect to find such basic magmas as form the monchiquites, producing glass when solidifying at such depths as they have in the cases which have come under our own observation, and in the instances which have been described by others. This anomaly is all the more marked when the acid dikes and intrusive sheets which so generally accompany them, and which must have been formed under similar conditions, are taken into account. As is well known the acid magmas crystallize with more difficulty than the basic ones; rhyolitic glasses are well known and are common, while tachylites are rare; at the same depths and under the same conditions which cause the very acid magmas to form extremely fine-grained dense or porphyritic rocks the basic magmas crystallize into moderate or even coarse-grained evenly granular ones. If the monchiquites contained so much glass

one would expect all the more to find the acid complementary forms — the oxyphyres — which accompany them also in, at least partly, glassy forms. This, however, is not the case in any of the regions, so far as we know, in which these rocks have been found, where erosion has cut down so as to expose the deeper-seated intrusive types.

The question thus raised on geological grounds concerning the glassy nature of the base was sought to be settled by other means. Since the microscope failed to yield any decisive results, recourse was had to chemical methods. In a number of samples that have been analyzed were some free from biotite and ægirite, and in which consequently all of the alkalis and presumably the alumina and water were in the base. In such cases it is noticed that the molecular ratios of these elements have approximately the relation:

$$Al_2O_3 : K_2O + Na_2O : H_2O :: 1 : 1 : 2.$$

If sufficient silica is deducted to satisfy the lime, iron and magnesia as pyroxene and olivine, the remainder has an approximately molecular relation to the above as follows:

$$S : O_2 : Al_2O_3 : Na_2O + K_2O + H_2O :: 4 : 1 : 1 : 2.$$

These, however, are the ratios given by the chemical formula of *analcite*. The results, of course, cannot be very accurate, as the exact composition of the crystallized minerals is not known, but are sufficiently close to show that grave doubts must exist concerning the glassy character of the base. Evidently to settle the question the base would have to be separated and analyzed. This has fortunately already been done by Hunter and Rosenbusch in their original investigation, and, as the results to be presently given will show, with great care and skill, on excellent material.

In separating the base from the included minerals by heavy solutions it was found impossible to obtain it absolutely free from microlites of ferro-magnesian minerals, and as Rosenbusch states, a portion of these were attacked by the acid used

in decomposing the substance and went into solution. The analysis by Hunter[1] gave the following results:

SiO_2	53.43	.890
Al_2O_3	20.86	.202
Fe_2O_3	2.61	.016
MgO	.29	.007
CaO	1.14	.020
Na_2O	11.63	.187
K_2O	2.51	.026
H_2O	7.06	.392
	99.53	

The substance just sank in the heavy liquid with specific gravity of 2.31, and this may be taken as being very close to its own specific gravity.

Of the above analysis about 96 per cent. is made up of silica, alumina, alkalies, and water, the rest is composed of the oxides of the microlites taken into solution. It will be seen that the oxides first mentioned are very close in their molecular ratios, given in the second column, to 4 : 1 : 1 : 2, but a slight excess of silica belonging to the lime, iron, and magnesia is present. The state of oxidation of the iron is uncertain, as it is not mentioned whether ferrous iron was determined or not. If we assume that the lime, iron, and magnesia are present according to the general formula of the amphibole group, $RSiO_3$, the microlites having been determined as amphibole, and deduct the requisite number of silica molecules to satisfy them, the remainder becomes

SiO_2	$.831 = 4.11 = 4$
Al_2O_3	$.202 = 1 \quad = 1$
$Na_2O + K_2O$	$.213 = 1.05 = 1$
H_2O	$.392 = 1.94 = 2$

The base has therefore the chemical composition $Na\,Al(SiO_3)_2\,H_2O$, with a little of the soda replaced by potash, or, in other words, it has *the exact chemical composition*, *the exact specific gravity*, *the property of gelatinizing with acids*, *and the optical*

[1] Op. cit., p. 454.

properties of analcite, and must therefore be that mineral and not a pitchstone glass, as had formerly been supposed.

The sharpness of the ratios given above is an excellent testimonial to the purity of the material, the care with which it was separated, and to the analytical skill of Hunter.

Thus the supposition that the base of these rocks was very unlikely to be a glass, and the indications previously mentioned that it was analcite, are most strikingly confirmed by these results. It is not to be wondered at that a base of analcite should have been mistaken for a glass by many petrographers, including the author, since, the grains having everywhere the same optical orientation and the same index of refraction, there would be no means of distinguishing them in plain or in polarized light, either from one another or from a continuous isotropic substance like glass. In the original monchiquites from Brazil, specimens and sections of which the author owes to the kindness of Professor Rosenbusch and of Professor A. Lacroix from material collected by Professor O. A. Derby, the analcite often shows a tendency to crystal form by the production of areas which are free from the larger prisms of the ferromagnesian minerals, the latter being arranged around them in wreaths. The areas thus resemble phenocrysts of leucite and they are in reality *phenocrysts of analcite*. They are sprinkled full of the microlites of hornblende described by Rosenbusch, which do not, however, show any tendency to the zonal arrangement shown by such inclusions in leucite.

It is a matter of great interest to recall in this connection that Lindgren[1] only a few months previous to Hunter and Rosenbusch had published an account of certain basaltic dikes occurring in the Highwood Mountains of Montana. They were shown to consist of augite, olivine, iron ore and analcite as phenocrysts in a groundmass of magnetite grains, augite microlites and a second generation of analcite.

The analcite was separated and two analyses were made which are given in I and II.

[1] Proc. Cal. Acad. Sci., Series 2, Vol. III, July 1890.

	I	II	Average	Molec. Ratios
SiO_2	54.90	49.87	52.38	.873
Al_2O_3	23.30	22.55	22.92	.222
Fe_2O_3	trace	1.51	0.75	.005
CaO	1.90	2.62	2.26	.040
MgO	0.70	1.28	0.99	.024
Na_2O	10.40	10.92	10.66	.171
K_2O	1.60	2.66	2.13	.022
H_2O	7.50	11.05	7.50	.416
	100.30	102.46	99.59	

Since the analyses were made on very small quantities the ordinary analytical errors become considerable and it is, therefore, probable that the average of the two would be more correct than either alone. The water in No. II is evidently too high and may be excluded. The average is shown in the third column and its molecular ratios in the fourth. The lime, iron and magnesia are of course due to admixed microlites of pyroxene, and deducting sufficient silica to turn them into the general formula $RSiO_3$ the remaining ratios have the following relations:

SiO_2 - - - - -	$.799 = 4.1 = 4$
Al_2O_3 - - - - -	$.222 = 1.1 = 1$
Na_2O+K_2O - - -	$.193 = 1.0 = 1$
H_2O - - - - -	$.416 = 2.1 = 2$

which gives the analcite formula Na Al $(SiO_3)_2H_2O$ with a fair degree of exactness, some of the soda being replaced by a little potash as in the Brazilian rocks.

In his article Lindgren[1] speaks of the difficulty of distinguishing the isotropic analcites from glass and in a review of the paper Iddings[2] emphasizes this point and suggests that isotropic minerals may have been determined as glass in some cases. It is now becoming evident how often this has, in all probability, been done.

It is now clear from what has been stated above that the

[1] Op. cit., p. 55.

[2] JOURNAL OF GEOLOGY, Vol. I, p. 638.

monchiquites of Rosenbusch and the analcite basalts of Lindgren are the same thing, the only difference being that the Highwood Mountain types are lacking in the amphibole found in the Brazilian ones.

In the Highwood Mountain types, as described by Lindgren, the analcite phenocrysts are sharply idiomorphic, which must have been one factor in preventing Lindgren from falling into the error concerning their nature which so many petrographers have committed. Moreover from this fact it would appear that the Highwood Mountain types are the best crystallized and most individualized type of monchiquites which have yet been described. Rosenbusch indeed classifies them with this group in the last edition of his Massige Gesteine.[1]

It now seems probable that analcite as a rock component is not limited strictly to the monchiquite group. The base described in basaltic rocks by Bücking[2] (*Basis zweiter Art*) as a colorless glass containing water, or which is stated to have the general composition of nephelite, that is, consisting of silica, alumina and soda and which gelatinizes readily with acids, is more than probably analcite, and it is quite possible that all of the colorless glasses which have been described as gelatinizing readily with acids have this composition. It seems very unlikely that a glass consisting of silica, alumina and soda would be readily attacked by acids and gelatinize; the basic glasses rich in lime, iron and magnesia and approaching a slag in composition, that is an approximation to the formula R_2SiO_4, are at times readily dissolved by acids, but it is strongly to be questioned if a soda-alumina glass would be. The determination of a colorless isotropic substance containing silica, water, soda and alumina and which gelatinizes with dilute acids in a rock is as safe a determination of analcite as that of the majority of minerals determined in eruptive rocks.

In the discussion of the primary or secondary nature of the

[1] Third edition, 1895, p. 542–543.

[2] Basaltische Gesteine, etc., Jahrb. k. k. preuss. geolog. Laudesanst. 1880 and 1881.

analcite in the rocks investigated by him, Lindgren was forced to conclude from the very fresh and unaltered character of the material that it must be of primary origin. The examination of the Highwood rocks by the author confirms this view of Lindgren's. Anyone who has seen the fresh unaltered character of the minerals in these rocks, not only from Montana but from Brazil and from other localities, would find it difficult to explain how the base could have undergone a thorough chemical change and decomposition throughout without the other minerals being affected in the slightest degree and especially the olivine, of all minerals perhaps the one most delicately susceptible to processes of hydration. It actually appears that henceforth we must accept analcite as an important and common rock-forming mineral, almost unquestionably one may say of primary origin. It is understood of course that its occurrence as a secondary mineral also, is not for a moment denied or its importance underrated. It must be said, however, in view of the facts now presented, that many cases where it has been called a secondary mineral are at least doubtful. Many authors for example cite it as secondary after leucite, and one gathers the impression from the context that this is supposed to have happened by weathering; though how leucite, which is a potash compound, is to change into analcite, a soda compound, by the simple addition of water, is not stated. It is true that Lemberg has shown that leucite is changed into analcite by the action of soda solutions; but, as in the case of the monchiquites, it can hardly be supposed that such an action could have taken place without altering the other minerals, and it would be difficult to see where so great a quantity of soda, as would be required, could have come from. It is also difficult to see how it could have formed from nephelite, norian or sodalite without the formation of other secondary products as noted above.

Lindgren[1] suggests that the mineral could have formed from igneous magmas, provided that the magma contained water and crystallized under sufficient pressure to retain it, and cites the

[1]Op. cit., p. 52.

presence of water in undoubted pitchstone glasses as a proof that water may be retained by igneous magmas at high temperatures. We believe this explanation to be the correct one and will present some further proofs of its probability.

The intimate relation between biotite on the one hand and olivine and leucite or orthoclase on the other was pointed out by Iddings[1] and has been further discussed by Bäckström[2] and the author.[3] Iddings and Bäckström point out that since for the production of biotite certain mineralizing agents, such as water and fluorine, are necessary, since they enter into its composition, the biotite rich rocks must be intrusive ones, whereas if the magma attains the surface and under the diminished pressure the water escapes, then olivine and leucite may be produced. By this is explained the general absence of leucite in abyssal rocks and its frequency in extrusive lavas. This process would of course find its most natural expression in magmas rich in magnesia and potash.

When we consider the magmas in which soda predominates however, it is clear that quite different processes will take place. There is no such relation between soda and magnesia as is shown by potash and magnesia in the biotite molecule. Therefore we might expect that if the magma contained water vapor and soda predominated in it, that analcite would be formed if the magma crystallized under pressure with considerable rapidity, whereas if the magma were anhydrous or the water vapor could escape without taking part in the crystallization either by relief of pressure or by very slow and gradual processes of crystallization, which would exclude it, then we should expect nephelite to form or nephelite and the albite molecule, the latter, perhaps, giving rise to plagioclase.

From this it would follow that the conditions most favorable for the production of primary analcitic rocks would be in dikes and small intrusions which is in fact the place where they occur,

[1] Origin Igneous Rocks, Bull. Phil. Soc., Washington, Vol. XII, p. 176, 1892.

[2] Geol. Fören. Förh., Stockholm, Vol. XVIII, p. 161, *seq.*, 1896.

[3] Highwood Mts. Bull. Geol. Soc. Am., Vol. VI, p. 409, 1895.

while the larger bodies of magma would tend to form theralites, ijolites, etc., and the surface lavas would appear as nephelite tephrites, basanites, basalts, nephelinites, etc.

As a corollary of this it would follow that all of these rocks should possess a general similarity of chemical composition, which in fact they do, as may be seen from the following table of analyses:

	I	II	III	IV	V	VI	VII	VIII	IX
SiO_2	46.48	43.74	43.50	43.85	43.17	51.03	44.85	42.12	42.88
Al_2O_3	16.16	14.82	18.06	15.25	15.24	8.48	18.08	14.35	13.99
Fe_2O_3	6.17	2.40	7.52	7.63	7.61	11.95	7.71	13.12	15.72
FeO	6.09	7.52	7.64	4.57	2.67	3.21	3.23		
MgO	4.02	6.98	3.47	4.47	5.81	6.34	4.16	6.14	3.94
CaO	7.35	10.81	13.39	8.54	10.63	6.96	9.97	13.00	12.64
Na_2O	5.85	3.08	2.00	4.22	5.68	5.42	3.19	4.11	4.73
K_2O	3.08	2.90	1.30	4.04	4.07	4.83	2.82	2.18	3.96
H_2O	4.27	2.94	1.22	1.80	3.57	1.68	2.56	3.42	3.08

I Monchiquite, Brazil (Hunter and Rosenbusch *op. cit.*), Hunter anal.

II Monchiquite, Brazil (Hunter and Rosenbusch *op. cit.*), P. Jannasch anal.

III Monchiquite, Magnet Cove, Ark. (Williams Igneous Rocks, Ark., 1890, p. 295), W. A. Noyes anal.

IV Monchiquite-Camptonite, Bohemia (Hibsch Tscher. Mitt. XIV, 1894, p. 101), F. Hanusch anal.

V Theralite, Crazy Mts., Montana (Wolff Petrog. Crazy Mts., 1885), J. E. Wolff anal.

VI Theralite, Crazy Mts., Montana (Wolff Petrog. Crazy Mts., 1885), A. M. Comey anal.

VII Nephelite tephrite, Bohemia (Hibsch *op. cit.*, p. 109), F. Pfohl anal.

VIII Nephelite basalt, Löbauer Berg, Heidepriem (Zirkel Petrog., 2d ed., Vol. III, p. 37).

IX Nephelinite, Laach., Eifel, vom Rath (Zirkel Petrog., 2d ed., Vol. III, p. 61).

The list might be greatly extended but the above are sufficient to show that the magmas producing these rocks have certain chemical characteristics in common, low silica, moderate alumina and alkalies with soda predominating over potash, and high lime, and iron, and high to moderate magnesia.

In this connection the author cannot refrain from pausing a moment to call the attention of petrographers to the fact, apparently not often recognized, that analyses of basic rocks, rich in

ferro-magnesian minerals, are very often vitiated by a failure to properly separate alumina from magnesia. Many analyses which would otherwise be good are spoiled by this error. The writer's attention has been strongly called to this point on examining, in connection with this article, various analyses of basic rocks. The types are described as consisting chiefly or largely of pyroxene with or without olivine and with the felspathoid components in perhaps subordinate quantity, yet the analyses may show very high alumina with very little magnesia. An example might be quoted of an analysis of this class published within the last few years:

SiO_2	Fe_2O_3,FeO	Al_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	Ign.
47.83	4.57	30.28	6.72	4.32	trace	1.30	2.19	2.05 = 99.26

In the light of our present knowledge this may almost be said to be an impossible composition for an igneous rock, and it is very clear that a large part of the magnesia must have been thrown down with the alumina. The tendency of alumina to drag down magnesia on precipitation with ammonia is very great and only to be prevented by the presence of a liberal quantity of ammonium salts, and the precipitation should always be repeated, especially where both oxides are present in considerable quantities, under which circumstances even a third precipitation may be necessary. There are many excellent chemists who, from a lack of experience in silicate analysis, fail properly to appreciate this point, and it has been perhaps the most common error in rock analyses.

Returning to our analcite rocks, it is of interest to observe in this connection that leucite and analcite have the same crystal form and the same structural formula except the addition of the molecule of water in the analcite; it is not strange that this difference between them should exist when one reflects how commonly soda salts contain water of crystallization and how much more rarely the potash compounds assume it.

The result of this is then to show why leucitic rocks are commonly effusive ones while the analcitic rocks would be more

commonly intrusive ones, though it is clear special cases might arise where the reverse was the case. Thus Cross[1] is inclined to view the analcite in phonolites described by him as of primary origin and the latest component to form, its formation being due to the local concentration of aqueous vapor produced by its exclusion where crystallization was progressing and by its accumulation in other spots.

The literature contains abundant references to the occurrence of analcite in igneous rocks, but in the great majority of them the rocks described are altered and unlike the beautifully fresh types whose discussion has served for the basis of this article, and it must therefore be uncertain whether the analcite is of primary or secondary origin. In some cases it would appear to be primary, but a discussion of them would carry us too far.

It is now clear (whether one accepts the primary origin of analcite or not) that we must recognize the analcite group of rocks just as we have the leucite group. The analcite basalts corresponding to the leucite basalts are the *Monchiquites* of Rosenbusch, the analcitites or olivine free analcite basalts are the *Fourchites* of J. Francis Williams.[2] The demonstration that the base of the monchiquite group is not glass but analcite does not in any sense impair its distinctness and individuality as a rock group, on the contrary it strengthens it by giving a definiteness of mineral composition that it did not before possess, and at the same time clears up what was one of the most puzzling questions in the petrography of igneous rocks occurring in these small intrusive masses.

And in conclusion we note also that the present case presents another example of how magmas, possessing similar chemical compositions, may form different mineralogical products when crystallizing under different physical conditions.

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Mineralogical-petrographical Laboratory,
Sheffield Scientific School, Yale University,
New Haven, May 1896.

[1] Geology Cripple Creek, XVI, Ann. Rep. U. S. G. S., Pt. II, p. 36, 1895.

[2] Igneous Rocks, Ark., p. 110, 1890.

THE QUEEN'S RIVER MORAINE IN RHODE ISLAND.[1]

In the autumn of 1894 Mr. F. C. Schrader and the first-named author of this paper, while traversing the western boundary of the Narragansett basin in Rhode Island, as members of Mr. N. S. Shaler's party, came upon an heretofore undescribed frontal moraine of large bowlders in the town of Exeter, R. I. This moraine is locally known in its strongest development on the south side of Shrub Hill on the farm of Mr. N. C. Reynolds as "Cat Rocks," and at another locality not far northward as "The Queen's Kitchen." (See Fig. 1.) Subsequent to this visit, Marbut undertook under the direction of the senior author to trace out this bowlder belt and to determine the indications, if any, of the front of the ice where the bowldery accumulation was feebly developed or wanting. In the following pages, are stated the observations of Woodworth regarding the moraine at Cat Rocks and of Marbut on the extension of the moraine north-eastward and southwestward.

The Queen's River bowlder belt is one of a series of well-developed moraines crossing southern Rhode Island. The outermost of these lines, that of Block Island, is imperfectly revealed. The next in succession northward, the Charlestown moraine, skirting the southern coast, is of the knob-and-basin type and is apparently submarginal in its origin. The Queen's River moraine lies at an average distance of twelve miles north of the last named. Investigation has not yet determined whether there is an intermediate moraine or not. All the moraines thus described lie west of a tolerably well marked interlobate axis passing northward from near Point Judith and thus west of East Greenwich toward Woonsocket. East of this line, the ice ran out through the Narragansett Bay depression in

[1] Published by permission of the Director of the United States Geological Survey.

the form of a lobe and west of the line indicated lay a wide but less well defined lobe of the ice-sheet. The general relations of the Queen's River moraine to the frontal deposits known in this field are shown on the accompanying sketch map of Rhode

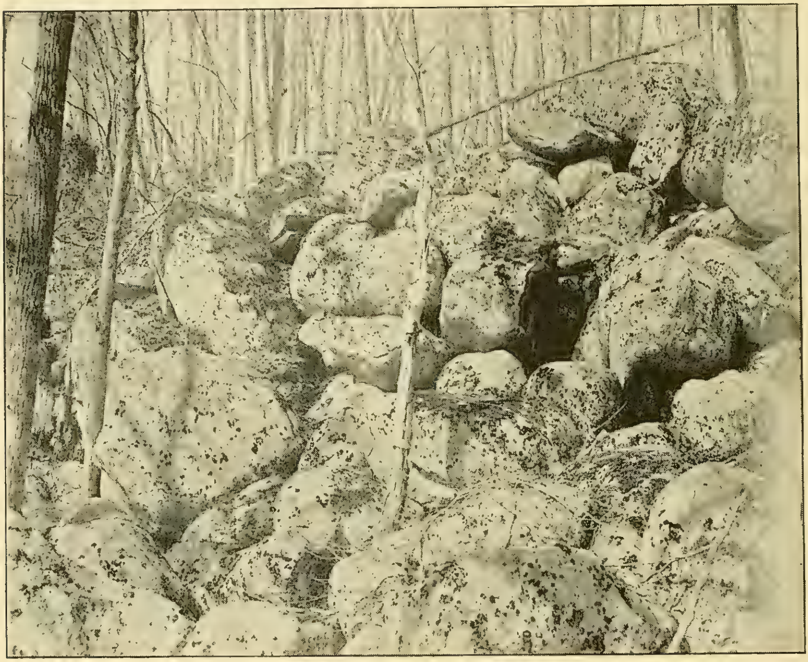

FIG. 1.—Queen's River Moraine, "Cat Rocks." View looking northeast from a point near the top showing the piling of bowlders successively from the north side.

Island (Fig. 2). The moraine is, in general terms, an upland phase of the sand-plains which mark the frontal stages of the ice-sheet in the Narragansett Bay region. The Queen's River moraine is probably contemporaneous with one of the frontal deposits which occur in the vicinity of Wickford Junction on the east side of the interlobate axis named.

Inasmuch as the bowlder belt at the Cat Rocks locality presents a form of accumulation capable of a somewhat extended diagnosis and furnishes criteria for determining the relations of

the deposit to the ice-sheet, the main features will be discussed somewhat at length.

The bowlder belt lies on the southern slope of Shrub Hill.—The accumulation of bowlders marking this moraine has taken place on the southern slope of a range of low crystalline hills forming the northern side of the river valley. The elevation above the

FIG. 2.—Sketch map of Rhode Island showing Queen's River bowlder belt. A, Cat Rocks in Exeter. B, Wickford Junction and Congdon Hill moraine. The small hachures northward indicate frontal deposits near East Greenwich.

stream varies from 20 to 100 feet. At Exeter the line crosses the river. Except for the excessive development of bowlder accumulations along this line, the surface deposits of till both north and south of the belt for several hundred feet would be classed as ground moraine, probably in part englacial till with subglacial material underlying it, the product of the melting out of an indefinite mass of ice.

The occurrence of bowlder belts in Southern New England on the crest of hills or on their southern slopes has been remarked elsewhere, as on Cape Ann by Shaler and Tarr, and on the southern slope of the highlands of Martha's Vine-

yard.[1] There appears to be a causal relation between the local conditions of this position and the deposition of the bowlders from the front of the ice-sheet. A brief analysis of the conditions which may be assumed to arise in such a position is appropriate in this place.

The stand of the ice front at the time of formation of the bowlder belt may be assumed to indicate that for the time being the rate of forward movement of the margin of the ice was equaled by the rate of melting back of the front. There are several reasons for believing that the ice was moving forward at this time. As will be presently explained in detail, the attitudes of some of the bowlders in the moraine at Exeter suggest the application of force in this manner. Had the ice been stagnant, the bowlders distributed in and under it or upon it, would have come to rest as a sheet of discrete bowlders instead of being brought up to a given line and there deposited.

The moraine was formed on that side of the valley which receives the larger amount of insolation. It is to be inferred from this that the same ice front lying upon the southern side of the valley with a less insolation to be reflected against the ice or received upon it would not have melted it back at a rate equal to the forward motion of the front; that the ice would, therefore, have moved over the crest to the next southern slope, where the insolation rate would again equal the forward movement and the ice be brought to a stand. On southern slopes the forward movement of the margin of the ice would be accelerated by gravity, on northward slopes retarded. But the tendency of a northward slope to retard would probably in time be overcome by the push of the ice from behind, while the acceleration on a southward slope would give an actually increased movement. With a balanced ice front on the northern side of the valley, it is therefore probable that the line of halt along the north side of Queen's River Valley indicates a slight advance of the ice front from the country on the north and not an

[1] See forthcoming atlas folio report on surface geology of Martha's Vineyard, by J. B. Woodworth.

immediately preceding retreat from the country lying south of the river.

To this consideration should be added the effect probably arising from the drainage in the valley which would tend to

FIG. 3.—View along the crest of Queen's River moraine showing its massiveness (here about 150 feet wide). The trees are growing from soil accumulated between the more closely set bowlders.

weaken and remove the ice in that position and to increase the frontal melting rate of an ice-sheet advancing into the stream from the north, so that the ice front would from this cause tend to rest along the northern bank. The elevation of the belt above the present stream does not preclude the existence of water at that height in glacial times.

Bowlders are scattered along the front of the belt.—South of the line of piled bowlders is a fringe from one to two rods wide

in which bowlders are scattered as if they had rolled out of a vanished cliff on the north. These fragments vary greatly in size. Their general appearance is shown in Fig. 3, a view taken from the crest of Cat Rocks.

Bowlder Couplets.—Within this fringe and particularly near the line where the materials begin to exhibit superposition, instances may be observed where bowlders occur in pairs: a

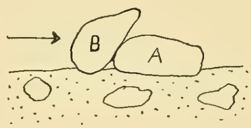

FIG. 4.—Bowlder Couplets. A, the stop; B, the stopped bowlder. The arrow indicates the direction of movement.

firmly settled bowlder has one leaning against it on the northern side, as indicated in the accompanying diagram (Fig. 4). These couplets appear best explained by supposing that the leaning bowlder tumbled outward from the ice and was stopped by coming into contact with the block on the south which had preceded it. The association of these colliding couplets with the scattered bowlders above described suggests the probability that the fringe as a whole is due to the falling out of bowlders from the ice front.

The structure of the main wall.—The belt at Cat Rocks is accumulated on a slope, so that while the crest is upwards of thirty feet above the frontal fringe by the roadside on the south, the elevation of the inner mural margin is not more than from three to six feet. The thickness of the belt, however, in places must be from ten to fifteen feet or even more, for the bottoms of the holes between the larger bowlders have not yet been reached with certainty. Many of these spaces are so large as to permit of the entrance of three or four persons with a little inconvenience. The absence of fine materials in the belt is very conspicuous. Although many trees are seen growing up out of the belt, most of them are probably growing out of a soil

which has formed in the lower part of the hollows and not from the soil proper of the surface on which the belt rests. One large oak has grown out of a crevice in a large bowlder, with a result in the end fatal to the tree.

FIG. 5.—View of the Queen's River moraine. "Cat Rocks," from the intraglacial field north of it, looking at the inner edge of the bowlder wall and showing the line along which the mural (?) front of the glacier stood.

The bowlders in many places along the frontal aspect of the moraine, as shown in Fig. 5, exhibit a mode of piling which seem to the writers accountable only on the supposition of addition from the north. Some of the bowlders may owe their peculiar orientation to a slight forward shoving movement. The general scheme of arrangement is shown in the annexed dia-

gram, Fig. 6, representing the highest part of Cat Rocks. The structure of the bowlder belt at Cat Rocks is, therefore, wholly consistent with the theory of its glacial origin, and the evidence of this exists not only in the main pile but also in the fringe above described.

It would throw some light on the mode of accumulation of these bowlders if it could be determined whether they were

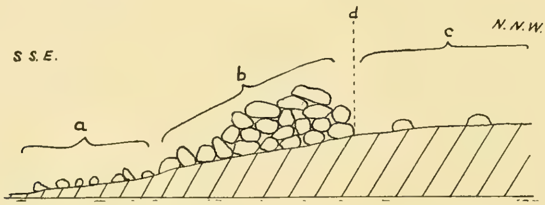

FIG. 6.—Diagrammatic section of highest part of Cat Rocks. A, zone of small scattered bowlders. B, zone of piled bowlders. C, zone of scattered bowlders left by the melting of the ice-sheet. D, position of the ice front.

dropped from an ice cliff as englacial or superglacial matter or were extruded from the base as subglacial débris. It was hoped that we might find criteria in the occurrence of bruised markings due to the violent contact of bowlders which had fallen out in the process of accumulation. The weathering of the blocks, which are largely gneisses and coarse granites, has, however, proceeded so far as to remove the original surface of the rocks where exposed to view, and the points of contact of the larger bowlders are not accessible for examination; so that this point has not been determined.

The northward or inner edge of the belt exhibits a mural contact with the ice front.—No feature in the distribution or accumulation of the bowlders at Cat Rocks is more suggestive of the glacial origin of the accumulation and of the particular relation of the deposit to the ice-sheet than the sharply defined northern wall which is here and there shown. The photograph reproduced in Fig. 5 is a view taken from the intraglacial field about seventy-five feet north of the moraine looking S. S. E. at this mural inner edge where best developed. Nowhere on the

southern side have we seen this phenomenon exactly reproduced. Evidently this mural face indicates the exact front of the ice-sheet at this locality. This wall is then the equivalent of the ice-contact slope at the head or northern side of glacial sand plains and esker-fans. North of this wall lies the intraglacial field, south of it the extraglacial field of that stage of the ice-sheet. It is a line supplying a base of reference from which to work out the relations to the ice-sheet of all associated deposits of the same stage.

North of the bowlder belt, bowlders are scattered as in ordinary ground-moraines.—The bedrock immediately back of the mural inner edge of the moraine is covered by till, the surface of which is pierced by a few scattered bowlders, usually smaller than those in the moraine. Fine materials are in excess. All the indications for hundreds of yards northward indicate a gradual melting down of the ice-sheet or a uniform retreat of the front so as to spread an even coating of till. As to whether the ice disappeared from this particular field by actual retreat of the front or by a general melting down of the whole mass, we have at present no criteria on which to base a decision. There are no indications of distinct submarginal accumulations of the nature of morainal mounds or kame-moraines interior to the frontal bowlder belt. But for the presence of the bowlder belt, one would not, we think, be able to demonstrate the halt of the ice front along this line.

The extraglacial field of the moraine.—South of the belt, there is a gentle slope to the valley of Queen's River, a small stream entering the Pawcatuck. This slope is till-covered to the upper limit of the stratified gravels and sands in the valley. Here and there patches of bowlders occur south of the main belt, in a few places running out like tongues from the moraine, as if along lines of maximum load in the retreating ice.

The outwashed gravels and sands of this stage were not in most of the area built up to the level of the base of the ice on the hillside, so that none of these deposits exhibit sand plains with ice-contact or kame-like slopes on their northern or ice-ward aspect.

Extension northeast of Cat Rocks.—The best development of moraine north of Cat Rocks is at the Queen's Kitchen, about a mile and a half northeast of the village of Exeter. The name is applied to the most northeasterly of a range of three small hills all of which are largely or wholly morainal. They lie on and rise above the surface of a long gentle, southeastwardly sloping plain. North of the moraine the plain is dotted with bowlders and contains many bowlder-filled swamps. South or southeast of the moraine, however, the surface is smoother, the valleys all contain water-laid drift, and bowlders are not so abundant. Bowlders occur occasionally in small patches especially in the heads of shallow valleys though they are of small size.

The moraine stands sharply above this plain, the highest of the three hills rising about sixty feet above the plain at its base. The most southwesterly of the three hills is lower and longer than the others, rising about thirty feet above the surface of the plain on which it stands. It is covered by till carrying a large number of bowlders. No outcrops of country rock were seen though they were not carefully hunted for. The trend of the hill, like that of the range, is about 25° east of north and its length is about 800 feet.

The middle member of the range is a small approximately conical hill about twenty-five feet high and not more than 200 feet in diameter at its base. It is not indicated on the Rhode Island topographic map. It lies about 300 feet north of the last one, and a little way back from a line joining the crests of the other two hills. It contains a larger proportion of bowlders than the last one.

The other member of the range, and the one to which the name Queen's Kitchen is applied, is the highest of the three. It lies about 1200 feet northeast of the crest of the first one described and rises about sixty feet above the plain at its base. Its whole surface is covered with large bowlders with no fine material near the surface. To all appearances the whole hill is merely a pile of bowlders varying considerably in size but all of them large. The northward slope is steep. The bowlders are not scattered out over the plain in this direction so that the

change from the even till plain to the bowlder-covered hill is sudden. The southern slope is more gradual. The bowlders are strung out southeastwardly from the foot of the hill for a distance of several hundred feet. At the foot of the northern slope there is a considerable accumulation of bowlders but they lie just at the foot of the hill and are not scattered out over the plain. They are in just the attitude that they would assume if they had been

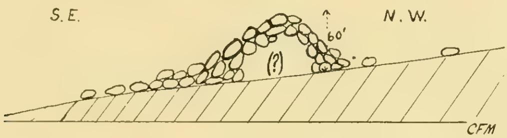

FIG. 7.—Diagram of the Queen's Kitchen phase of the moraine.

piled up against the steep front of the ice and had fallen down when the ice receded.

At Cat Rocks the moraine is accumulated on a locally steeper slope than the general slope of the plain, so that the top of the accumulation rises little if any above the level of the plain on its northern side while at Queen's Kitchen the moraine rises sharply above the plain on all sides. (Fig. 7.)

Between Cat Rocks and the Queen's Kitchen no well-defined bowlder moraine exists. There is, however, a well-defined southern limit in the bowlder-dotted till plain lying north of the supposed position of the ice front. To the south of an irregular line connecting the two localities, the surface drift is water-laid; to the north it is ice-laid. South of this line, bowlders are never seen, excepting scattered ones lying on the higher lands. North of it they are thickly strewn over the surface. It does not appear that the thickly bowlder-covered phase of the till plain extends southward beneath the gravel and sand deposits. South of the northern border of the water-laid drift there are numerous hills which rise well above the level of this deposit, but they carry few bowlders. They all have a smooth outline with only a veneer of drift and the country rock is exposed in many places on them.

North of the Queen's Kitchen there is no prominent bowlder

accumulation along the line of the moraine, though the line limiting the bowlder-dotted till plain on the one hand and the sand and gravel plain on the other is more marked, for a short distance, than it is between Cat Rocks and the Queen's Kitchen.

From the latter place the moraine turns almost due northward and is easily traced for about two miles. It lies along the slope where the higher till-covered plain west of the moraine descends to the lower sand-covered plain east of it. Bowlders are scattered thickly over the slope but they are accumulated very little more along the outer margin than further back. Spurs of the upland, however, which extend out eastward beyond the moraine do not carry many bowlders.

About half a mile south of Frenchtown, the line apparently turns westward along the southern slope of a valley occupied by an eastward flowing stream. An attempt was made to find the moraine north of the valley but it could not be found. The country as far north as Natick on the Pawtuxet River was searched but it was not found. The river was followed up to half a mile above Coventry. Here a line of bowlders crosses the river, having a northwesterly trend, but no attempt was made to follow it in either direction.

Extension south of Cat Rocks.—The moraine was traced southwestward from Cat Rocks to within about three miles of Wyoming in the town of Richmond. Over the greater part of the distance it is a fairly-well marked feature, though it never assumes the phase so well developed at Cat Rocks. As a rule, the relations of the morainal and the extramorainal areas are essentially the same as they are north of Cat Rocks. North and northwest of a somewhat irregular line lies a plain of typical bowlder till on which bowlders are most abundant along the southern margin; south and southeast of it lies a region whose valleys are partly filled with water-laid drift, and whose higher lands consist of rounded hills and ridges carrying very few bowlders. The general relief is the same on both sides of the line. The glacial deposits are not thick enough to hide the preglacial topography. The contrast in appearance between the

plains on the two sides of the ice margin is merely one of surface character. One is smooth, the other is bowlder-covered.

From Cat Rocks southwestward for about two miles the southern margin of the till plain is not sharply defined. It graduates southward into the sand and gravel plain, and bowlders are nowhere abundant. This phase is succeeded by a belt extending southwestward to within one and a half miles of Glen Rock village. The southern border of the till plain is characterized by a thick accumulation of bowlders, almost entirely covering the surface, but not piled up into a ridge. The margin lies along the southern slope of a hill, but it lies north of the northern border of the water-laid drift. Occasional patches of bowlders lie between the margin of the bowlder belt and the northern margin of the water-laid drift.

About a mile and a half north of Glen Rock village, the moraine turns westward, crossing Beaver River at Hillsdale. The upland east of Hillsdale is covered with bowlders and the streams are all filled with them. The ponding of the head waters of a small brook which flows into Queen's River at Glen Rock is probably due to morainal accumulations.

Between Hillsdale and the schoolhouse, a mile and a half north of Glen Rock, the moraine is not so well defined as it is further eastward. The bowlders are neither so abundant nor so large. At Hillsdale, however, it again becomes a characteristic bowlder belt. The morainal accumulation consisting mostly of bowlders has ponded the river. The power thus made available was formerly utilized in manufacturing. Down stream from the moraine the valley is filled up to the level of the foot of the moraine with a broad sand plain, but north of it the valley is filled with bowlders. On the slope of the western side of the river valley just back of the village there is an accumulation of very large bowlders, approaching the phase of the moraine developed at Cat Rocks. From this point westward as far as the moraine was traced its development was weak.

J. B. WOODWORTH.

C. F. MARBUT.

Studies for Students.

THE PRINCIPLES OF ROCK WEATHERING.

1. Preliminary generalities.
2. Agencies engaged in Promoting Rock weathering.
    (*a*) Action of the Atmosphere.
    (*b*) Chemical Action of Water.
    (*c*) Mechanical Action of Water and of Ice.
3. Analyses of Fresh and Decomposed Rocks.
4. Discussion of Results and Résumé.

(1) PRELIMINARY GENERALITIES.

In the series of papers to be given under the above title it is proposed to discuss briefly the principles involved in the breaking down of rock-masses when subjected to the ever varying conditions commonly grouped under the name of "weathering."

So striking a phenomenon as the disintegration of a mass of firm rock, naturally did not escape the observation of the earlier workers in geology, and the older literature, from the time of Hutton, bears numerous references to it, though the full significance of atmospheric agencies in bringing about the result, seems not at first to have been fully realized. Indeed the earliest satisfactory accounts to which we have access, are those of writers of the present century, which are based largely upon observations made in moist and warm climates, where the results of such weathering are most apparent.

The exciting cause of this degeneration has been a matter of considerable speculation, and, before proceeding further, it may be well to indicate in brief their tendencies.

Fournet, as quoted elsewhere, writing as early as 1833, insisted upon the efficacy of water containing carbonic acid in

promoting the decomposition of igneous rocks, while Brongniart, writing with particular reference to feldspathic decomposition and the origin of kaolin, laid great stress on the acceleration of the ordinary processes of decay through the electric currents resulting from the contact of heterogeneous rock-masses. Darwin[1] believed the extensive decomposition observed by him in Brazil, to have taken place under the sea, and before the present valleys were excavated. Hartt[2] gave it as his opinion that the decomposition was due to the action of warm rain water soaking through the rock and carrying with it carbonic acid derived not only from the air, but from the vegetation decaying in the soil as well, together with organic acids, nitrate of ammonium, etc. Further that the decomposition had gone on only in regions once covered by forests. Heusser and Claraz,[3] suggest that the decomposition was brought about through the influence of nitric acid. They say "it is without doubt determined by the violence and frequency of the tropical rains, and by the dissolving action of water, which increases with the temperature. It is necessary to observe, moreover, that this water contains some nitric acid, on account of the thunder storms which follow each other with great regularity during many months of the year."

Belt[4] in discussing the extensive decomposition observed by him in Nicaragua says "This decomposition of the rocks near the surface prevails in many parts of tropical America, and is principally, if not always, confined to the forest regions. It has been ascribed, and probably with reason, to the percolation through the rocks, of rain water charged with a little acid, from the decomposing vegetation."

The elder Agassiz[5] laid much stress on the decomposing effects of hot water from rainfall, while Mills[6] attributed no

[1] Geological Observations, p. 417.

[2] Physical Geography and Geology of Brazil.

[3] Ann. des Mines, 5^e Series, 17^e, 1860.

[4] The Naturalist in Nicaragua. 1874.

[5] Jour. in Brazil, p. 89.

[6] Am. Geologist, June 1889, p. 351.

insignificant amount of the decomposition to the action of carbonic acid produced through the instrumentality of ants.

The chemical changes involved in the process of decomposition received attention from several of the earlier workers, among whom the names of Berthier, J. G. Forschhammer, Brongniart, Gustav Bischof and Ebelmen stand out in greater prominence. More recently the name of Sterry Hunt becomes conspicuous, while the purely geological side of the question has been set forth in numerous papers by De La Beche, L. Agassiz, R. Pumpelly, N. S. Shaler, O. A. Derby, J. C. Branner and others, to whom reference is made in these pages.

(2) THE AGENCIES ENGAGED IN PROMOTING ROCKWEATHERING.

The expression "rockweathering" as commonly used, is a comprehensive term descriptive of the processes which are so constantly engaged in degrading rock-masses and reducing them to the condition of gravel, sand, and clay, and incidentally to soil. These processes are in part physical and in part chemical in their nature; at times simple, and yet again complex. But, whatever the forces engaged, they are, with a few isolated exceptions, superficial — they work from the surface downwards. However much they may have accomplished since the first rock-masses appeared above the primeval ocean, in no case can the actual amount of débris in situ, have formed at one time more than a scarcely appreciable film over the underlying and unchanged material. The decomposing forces early lose their active principles, and become quite inert at depths comparatively insignificant. It is only where through erosion the results of the disintegration are gradually removed, that the processes have gone on to such an extent as to perhaps quite obliterate thousands of feet of massive rock, and furnished the necessary débris for the great thicknesses of sandstone, slate, and shale, which characterize the more modern horizons. In certain isolated cases, it is true, ascending steam and heated waters arising from unknown depths, have been instrumental in promoting decomposition, as is well illustrated in the areas of decomposed

rhyolites in the Yellowstone National Park. Nevertheless, it is to the exceedingly slow process of superficial weathering that we owe a very large share of the apparent rock decomposition and incidental soil formation.[1]

Were it possible it might be well in this discussion to describe each of the involved processes in detail, both in relation to its mode of operation and the results produced. From the fact however, that any one, either physical or chemical, rarely goes on alone, it is thought best to treat the subject as below, and describe in more or less detail the action of (1) the atmosphere, (2) of water in both the solid and liquid form, and (3) that of plant and animal life, finally considering the combined action of all these forces, as manifested on the various types of rock which go to make up the earth's crust.

(*a*) ACTION OF THE ATMOSPHERE.

Pure dry air under constant conditions of heat or cold, can have, but little effect upon rock-masses either in producing physical or chemical changes. Aided, however, by moisture and temperature variations, it becomes a powerful agent for disintegration as well as for transportation.

In its normal state atmospheric air, as is well known, is a mechanical admixture of four volumes of nitrogen to one of

[1] The reader must keep clearly in mind the distinction between the words *alteration* (Ger. Umwandlung), and *decomposition* (Ger. Verwitterung or Zersetzung) as here used. The one is a more or less deep-seated chemical and molecular process through which a rock may undergo a complete change so far as its mineralogical or lithological nature is concerned while yet retaining its geological identity, as where augite becomes altered to uralitic hornblende, or an eruptive olivine rock (peridotite) becomes altered into serpentine. The second is a wholly superficial change brought about through external agencies and resulting in a more or less complete destruction of the original compounds, loss of material and general breaking down of the mass as a geological body, as when granitic rocks decompose to the condition of quartz sand and kaolin, with the separation of free calcium and alkaline carbonates and oxids of iron and manganese. The line of distinction to be sure cannot in nature be always sharply drawn, and indeed alteration is often but a preliminary to decomposition, though this is by no means universally true, as is shown by the superior resisting power of certain trappean rocks in which the pyroxenic and feldspathic constituents have altered into hard, tough aggregates of free quartz, chlorite and epidote.

oxygen, with minute quantities of carbonic acid (from 2.5 to 3.5 parts in 10,000), and in the vicinity of large cities and in volcanic regions, of appreciable quantities of sulphuric and hydrochloric acids as well. With rare exceptions these last may be considered as existing not as free acids, but in combination as sulphates, and chlorides. This, in addition to their limited distribution justifies us in largely ignoring them in the present discussion.

Nitric acid, nitrogen and ammonia.—Much has from time to time been written regarding the occurrence of nitric acid in the atmosphere, and its supposed significance in relation to the subject under discussion. It seems now, however, to be the generally accepted opinion among chemists, that *free* nitric acid in the atmosphere is a thing of comparative rare occurrence and if occurring at all, is present only in very minute quantities. The researches of Boussingault, Cloez, De Luca and others did, it is true, indicate the presence of the acid, but as ammonia is also almost invariably present in amounts sufficient or even in excess of that needed to combine with it as a nitrate, the conclusion seems unavoidable that in the large majority of cases the presence of free nitric acid is impossible, or it exists only momentarily during times of great electrical disturbance (as during thunder showers). As nitrate of ammonia its presence is almost universal. It is probable that neither these gases nor their salts have any direct influence in promoting rock decomposition. It has been demonstrated, however, that nitrogen compounds and nitrogenous matter in the soil, may become subject to nitrification through the action of bacteria, whereby ammonia, nitrous or nitric acid, carbon dioxide and water are formed, though as Wiley says, "The ammonia and nitrous acid may not *appear* in the soils, as the nitric organism attacks the latter at once and converts it into nitric acid."[1] (See further under Influence of Plant and Animal Life.)

In considering the efficacy of these agents as rock destroyers we must not lose sight of the fact that the supply of nitrogen in the soils is as a rule far too small to supply the demands of

[1] Wiley, Principles and Practice of Agricultural Analysis.

growing plants and it is probable that a very large proportion of that which finds its way there, is quickly taken up again by these organisms, and but little is left to promote decay. It is possible that other salts of ammonium than the nitrate may be locally efficacious. Thus M. Beyer as quoted by Van Den Broeck[1] has shown that the feldspars decompose very rapidly under the influence of water containing ammonium sulphate or even sodium chloride, either of which substance may be found in vegetable soil.

Carbonic acid.—The amount of carbonic acid in the air under natural conditions is not a widely variable quantity excepting near volcanoes and the immediate vicinity of gaseous springs. This has been pretty thoroughly demonstrated by Muntz and Aubin.[2] In the vicinity of large cities and manufactories consuming great quantities of coal the amount is naturally increased. Although carbonic acid is the most abundant gas given off by decomposing vegetable matter, it has apparently been definitely ascertained that the amount of this gas in the atmospheres of regions of abundant vegetation is no greater than elsewhere. This has been accounted for on the assumption that the gas as fast as liberated is taken up by growing organisms or carried by rains into the soil. Twenty-one tests of the air in various parts of Boston during the spring of 1870, showed the presence of 385 parts of carbonic acid in 1,000,000.

Eleven tests of the winter air in Cambridge yielded 337 parts in 1,000,000.[3] Dr. J. H. Kidder found the out-door air of Washington to contain 387 to 448 parts in 1,000,000, while Dr. Agnus Smith after an elaborate series of experiments, reported the atmosphere of Manchester (England) as containing 442 parts in 1,000,000.[4] These tests are all of atmospheres in the vicinity of cities. Muntz and Aubin, quoted above, found a

[1] Mem. Sur. Les Phenomes D'Alteration Des Depots Superficial, p. 16.

[2] MUNTZ and AUBIN. Comptes Rendus. 93. 1881, p. 797. Also 96. 1883. pp. 1793–97.

[3] Second Annual Report Massachusetts State Board of Health. 1871.

[4] Air and Rain, p. 52.

general mean of 278 parts in a million for stations in Florida, Mexico, Haiti, Chile and Patagonia, and 296 parts in the north of France. Fischer as quoted by Branner[1] has shown that in rain and snow water the amount of carbonic acid varies between 0.22 per cent. and 0.45 per cent. by volume of water. Assuming that the mean of these figures fairly represent the general average, it is easy, knowing the rainfall of any region to calculate the amount of gas thus annually brought to the surface. Professor Branner has thus calculated that from 3.21 to 11.80 millimeters of carbonic acid gas (CO_2) are annually brought to the surface in certain parts of Brazil. The same method of calculation applied to the various parts of the United States, would give us for the Atlantic coast states $3^{mm}.75$; for the upper Mississippi Valley $2^{mm}.5$; for the Lower Mississippi Valley $4^{mm}.5$, and for the northern Pacific states $6^{mm}.25$. As it is mainly when this carbonic acid is thus brought to the surface by rain and snows that its effects become of direct significance in our present work, we may drop the matter here, to be taken up again when considering the chemical action of water.

Oxygen.—Under ordinary conditions oxygen is the most active principle in the atmosphere, and it is to this agent that we owe the process of oxidation whereby silicates and other minerals containing iron in the protoxide state undergo decomposition. Even here, however, oxidation is almost inactive unless aided by moisture and a further discussion of the subject may well be deferred to be taken up again when discussing the action of water.

Heat and cold.—The ordinarily feeble action of the air is greatly augmented through natural temperature variations. That heat expands and cold contracts is a fact too well known to need elaboration here. That however the constant expansion and contraction due to diurnal temperature variations may be productive of weakness and ultimate disintegration in so inert a body as stone, seems not so generally understood, or is at least less well appreciated, and hence a little space is devoted to the

[1] Bull. Geol. Soc. of Am., Vol. VII, 1896, p. 305.

subject here. Rocks, it must be remembered, as the writer has noted elsewhere,[1] are complex mineral aggregates of low conducting power, each individual constituent of which possesses its own ratio of expansion, or contraction, as the case may be. In crystalline rocks these various constituents are practically in contact. In clastic rocks they are, on the other hand, frequently separated from one another by the interposition of a thin layer of calcareous, ferruginous or siliceous matter which serves as a cement. As temperatures rise, each and every constituent expands and crowds with almost resistless force against its neighbor; as temperatures fall, a corresponding contraction takes place. Since in but few regions are surface temperatures constant for any great period of time, it will be readily perceived that almost the world over there must be continuous movement within the superficial portions of the mass of a rock. The actual amount of expansion and contraction of stone under ordinary temperatures, has been a matter of experiment. W. H. Bartlett[2] has shown that the average rate of expansion for granite amounts to .000004825 inch, per inch of stone, for each degree Fahrenheit; for marble .000005668 inch, and for sandstone .000009532 inch. Adie, in a series of similar experiments found the rate of expansion for granite to be .00000438 inch, and for white marble .00000613 inch.[3]

Shaler states[4] that rock surfaces in the eastern United States may be subjected to temperatures varying from 150° F. at midday in summer, to 0° and below in winter. This change of 150° in a sheet of granite 100 feet in diameter would produce a lateral expansion of 0.8685 inch of surface. That this expansion must tend to lessen the cohesion and tear the upper from the deeper lying layers, is self-evident. As exemplifying this, Professor Shaler states that there are on Cape Ann (Massachusetts) hundreds of acres of bare rock surface completely

[1] Stones for Building and Decoration, WILEY & SONS, New York.

[2] Am. Jour. Science, Vol. XXII, 1832, p. 136.

[3] Trans. Royal Soc. of Edinburgh, XIII, p. 366.

[4] Proc. Boston Soc. Natural History, XII, 1869, p. 292.

covered with blocks of stone which have been separated from the mass beneath by just this process.[1]

It is natural that this form of disintegration should be most pronounced in massive, close-grained rocks. In regions of great extremes of daily temperature, the rupturing of these masses from the parent ledge is frequently attended by gun-like reports sufficiently loud to be heard at a considerable distance. H. von Streeruwitz states[2] that the rocks of the Trans Pecos (Texas) region undergo a very rapid disintegration from diurnal temperture variations, which here amount to from 60° to 75° F. He says, "I frequently observed in summer, as well as in winter time, on the heights of the Quitman Mountains, a peculiar crackling noise, and occasionally loud reports . . . . and careful research revealed the fact that the crackling was caused by the gradual disintegration and separation of scales from the surface of the rock, and the loud reports of crackling and splitting of huge bowlders." The scales thus split off, he says, vary in thickness from one-half to four inches, and their superficial area from a few square inches to many feet. This form of disintegration is necessarily confined to slopes unprotected by vegetation, and is the more pronounced the greater the diurnal vegetation. Dr. Livingston reports that in certain parts of Africa the rock temperatures on the immediate surface rise during the day as high as 137° F., and at night fall so rapidly as to throw off by their contraction sharp angular masses in sizes up to 200 pounds weight. Throughout the desert regions of Lower California, as observed by the writer, the granitic and basic eruptive

[1] The rifting action of heat upon granitic masses is said to have been made a matter of quarry in India. It is stated (*Nature*, January 17, 1895,) that a wood fire built upon the surface of the granite ledge, and pushed slowly forward, causes the stone to rift out in sheets six inches or so in thickness and of almost any desired superficial area. Slabs 60 x 40 feet in area have been thus obtained varying not more than half an inch from a uniform thickness throughout. In one instance mentioned the surface passed over by the line of fires was 460 feet, setting free an area of stone of 740 square feet of an average thickness of five inches. This stone was undoubtedly one of remarkably easy rift, but the case will nevertheless serve our present purposes of illustration.

[2] Fourth Ann. Rep. Geol. Survey of Texas, 1892, p. 144.

rocks, subjected to very little rainfall, and hence almost completely bare of vegetation, have, under the blistering heat of the desert sun, weathered down into dome shaped masses, their débris in the form of angular bits of gravel being strewn over the plain. Particles of this gravel when compared with those which are a product of chemical agencies are found to differ in that each, however friable, is a complex molecule of quartz, feldspar and mica or whatever may be the mineral composition of the rock from which it derived. Aside from a whitening of the feldspathic constituent, due to the reflection of the light from its parted cleavage planes, scarcely any change has taken place, and indeed it more resembles the finely comminuted material from a rock crusher than a product of natural agencies.

Owing however to the low conducting power of rocks, disintegration from this cause alone can go on to any extent only at the immediate surface, and on flat and level planes where the débris is allowed to accumulate must in time completely cease.[1]

It is only on hillsides and slopes or where by the erosive action of running water, or by wind, the débris is gradually removed that such can have any geological significance, although the rate of such disintegration is sufficiently rapid in exposed places to be of serious consequence in stone used for architectural application. (See further under Action of Ice.)

[1] Observations by FORBES (Trans. Royal Society of Edinburgh, Vol. XVI, 1849), showed that at depths of not above twenty-five feet the mean annual temperature was greater than near the surface, these results being confirmatory of those obtained by QUETELET at Brussels. The following tables from FORBES' paper show maximum range of temperatures at varying depths and also the depths at which the annual range is reduced to 0°. 01 centigrade.

I. SHOWING RANGE OF TEMPERATURES FAHR.

Year 1841–1842	Trappean Rock Observatory			Sand Experimental Garden		
Depth	Max.	Min.	Range	Max.	Min.	Range
3 ft	52.85	38.88	13.97	54.50	37.85	17.65
6 "	51.07	40.78	10.29	52.95	39.55	13.40
12 "	49.0	44.2	4.8	50.4	43.5	6.9
24 "	47.5	46.12	1.38	48.1	46.1	2.0

But it is to the action of the air when in motion — to the wind — that is due a very effective part of atmospheric work. Particles of sand drifting along before the wind become themselves agents of abrasion, filing away on every hard object with which they come in contact. As a matter of course this phenomenon is most strikingly active in the arid regions, though the results, when looked for, are by no means wanting in the humid east. It is thought by Professor Egleston that many of the tombstones in the older churchyards of New York City, have become illegible by the wearing action of the dust and sand blown against them from the street. There is among the heterogeneous collections of the National Museum, at Washington, a

Sandstone Craigleigh		
Max.	Min.	Range
53.15	38.25	14.9
51.9	38.95	12.95
50.3	41.6	8.7
48.25	44.35	3.9

II. SHOWING DEPTHS AT WHICH THE ANNUAL RANGE IS REDUCED TO 0°.01 CENT.

Year	Trappean Rock Observatory	Sand Experimental Garden	Sandstone Craigleigh
1837	58.1	72.2	97.3
1838	49.3	61.8	91.0
1839	59.2	63.5	100.0
1840	55.9	67.1	98.8
1841	63.9	68.3	107.4
Mean	57.3	66.6	98.9

Observations on soil temperatures made at the Orono (Maine), Experimental Station, showed the mean daily range of temperatures from April to October, at a depth of 3 inches to be 5°.26; at 6 inches 1°.9; at 9 inches 1°.18; and at 12 inches very slight. At a depth of 1 inch the temperature was lower than that of the air by 2°.4; at 3 inches, by 2°.11; at 6 inches, by 3°.16; at 9 inches, by 3°.94; at 12 inches, by 4°.18; at 24 inches, by 5°.78; and at 36 inches by 7°.10.

The remarkable uniformity of temperatures at comparatively slight depths below the surface is also well illustrated by limestone caverns and in mines. The highest summer temperature of Mammoth Cave being reported as 56° F. and the lowest winter as 52°.5. The mean for the summer being 54° and for the winter 53°.

large sheet of plate glass, once a window in a lighthouse on Cape Cod. During a severe storm of not above forty-eight hours' duration this became on its exposed surface so ground from the impact of grains of sand blown against it, as to be no longer transparent and to necessitate its removal.

Window panes in the dwelling houses of the vicinity are, it is even stated, not infrequently drilled quite through by the same means.

Apply now this agency to a geological field in a dry region. The wind sweeping across a country bare of verdure and parched by drouth, catches up the loose particles of dust and sand and drives them violently into the air in clouds, or sweeps them along more quietly close to the surface where they are at first scarcely noticeable. The impact of a single one of these moving grains on any object with which it may come in contact, is far too small to be appreciable, but the impact of millions acting through days, weeks and years, produces results not merely noticeable but strikingly conspicuous. We have here in fact a natural sand blast, an illustration on a grand scale of a principle in common use in glass cutting and to a small extent in stone cutting also. Constantly filing away on every object with which they come in contact the grains go sweeping on, undermining cliffs, scouring down mountain passes, wearing away the loose bowlders and smoothing out all inequalities. Naturally the abrading action on exposed blocks of stone is most rapid near the ground, as here the flying sand grains are thickest. First the sharp angles and corners are worn away, and the masses gradually become pear shaped, standing on their smaller ends. Finally the base becomes too small for support, the stone topples over, and the process begins anew without a moment's intercession and continues until the entire mass disappears—becomes itself converted into loose sand drifted by the wind and an agent for destruction. W. P. Blake was the first, I believe, to call public attention to this phenomenon, having observed it while in the pass of San Bernardino (California) in 1853. G. K. Gilbert has also published some interesting facts as noted by him-

self while geologist of the Wheeler Expedition west of the 100th meridian in 1878. In acting on the hard rocks the sand cuts so slowly as at times to produce only grooved or fantastically carved surfaces often with a very high polish. The geologists of the 40th Parallel Survey in 1878 described like interesting phenomena as observed on the western faces of conglomerate bowlders exposed to the sand blasts of the desert regions of Nevada. The surface of the otherwise light colored rock was found to have assumed a dark lead gray hue and a polish equal to that of glass, while the sand had drilled irregular holes and grooves, often three-fourths of an inch deep and not more than an eighth of an inch in diameter, through pebbles and matrix alike.

Even the humid east is not without its illustrations of natural sand-blast carvings. On the shores of Cape Elizabeth, Maine, the cliffs facing toward the open sea are often riddled with peculiarly irregular holes formed by the gyrations of sand grains blown up from the beach below and kept spasmodically in motion by the wind.

(*b*) CHEMICAL ACTION OF WATER.

Pure water, although an almost universal solvent, nevertheless acts with such slowness upon the ordinary materials of the earth's crust that its results are scarcely appreciable to the ordinary observer. It by no means follows, however, that its effects are not worthy of our consideration here. This is particularly true when we reflect that the results we are discussing are not merely those of days and weeks, but of years even when counted by the tens of thousands and millions. Moreover absolutely pure water, as a constituent of our earth and its atmosphere, presumably does not exist. We have to consider its action as well when contaminated with sundry salts and acids which it almost universally holds, having taken them up in passing through the atmosphere and in filtering through the overlying layer of organic matter and decomposition products which cover so large a portion of the surface of the land. It is when thus contaminated, then, that are manifested the wonder-

ful solvent and other chemical reactions which have been instrumental in promoting rock destruction, and it is here, then, that we will consider the complex chemical processes commonly grouped under the head of oxidation, deoxidation, hydration, and solution.

Oxidation.— Oxidation is perceptibly manifested only in rocks carrying iron either as sulphide, protoxide carbonate, or silicate. The sulphides, in presence of water and when not fully protected from atmospheric influences, readily succumb, producing sulphates, which being soluble are rapidly removed in solution, or hydrated oxides, sulphuretted hydrogen, and perhaps free sulphur. Such an oxidation is attended by an increase in bulk so that if nothing escapes by solution there may be brought to bear a physical agency to aid in disintegration. Weathered rocks containing iron sulphides may not infrequently be found with cubical cavities quite empty or partially filled with the brownish, yellow, or red product of their oxidation, in a more or less powdery condition. Pyrites, though a widespread constituent, is nevertheless a less conspicuous agent in promoting rock decomposition than the protoxide carbonates and silicates. In these the iron passes also over to the hydrated sesquioxide state, as is indicated by the general discoloration whereby the rock becomes first streaked and stained and finally uniformly ochreous. The more common minerals thus attacked are the ferruginous carbonates of lime and magnesia and silicates of the mica, amphibole, and pyroxene groups. As the oxidation progresses the minerals become gradually decomposed and fall away into unrecognizable forms. The red and yellow colors of soils are due invariably to the iron oxides contained by them.

Deoxidation is a less common feature than oxidation. Water carrying quantities of organic acids may, through their influence, take away a portion of the combined oxygen of a sesquioxide, converting it once more into the protoxide state, in which form it may be dissolved and removed as a ferrous carbonate or sulphate. The local bleaching of certain ferruginous

sands and sandstones is due to this action. Through a similar process of deoxidation ferrous sulphates may be converted into sulphides, a process which undoubtedly takes place in marine muds protected by the water from atmospheric action. *Hydration*—the assumption of water—more commonly accompanies oxidation, and indeed is an almost constant accompaniment of rock decomposition, as may be observed in comparing the total percentages of water in fresh and decomposed minerals and rocks, as given in any series of analyses. The amount of water thus taken up is in some cases surprisingly large. This assumption, provided it be not accompanied with an equal loss of other constituents, is attended with an increase in bulk such as may be quite appreciable. In cases where rock disintegration progresses without serious decomposition or surface erosion a corresponding expansion must also take place. The Comte de la Hure, as quoted by Branner,[1] has expressed the opinion that some of the hills of Brazil have actually increased in height through this means. The present writer has calculated that the transition of the granitic rock of the District of Columbia into arable soil must be attended by an increase in bulk amounting to 88 per cent.

Hydration as a factor in rock disintegration is, in the writer's opinion, of more importance than is ordinarily supposed. Granitic rocks in the District of Columbia have been shown[2] to have become disintegrated for a depth of many feet with loss of but some 13.46 per cent. of their chemical constituents and with apparently but little change in their form of combination. Aside from its state of disintegration the newly-formed soil differs from the massive rock mainly in that its feldspathic and other silicate constituents have undergone a certain amount of hydration. Natural joint blocks of the rock brought up from shafts excavated during the extension of the city waterworks were, on casual inspection, sound and fresh. It was noted, however, that on exposure to the atmosphere such

[1] Bull. Geol. Soc. of America, Vol. VII, 1896, p. 284.

[2] MERRILL, Bull. Geol. Soc. of America, Vol. VI, p. 341, and Vol. VII, p. 357.

not infrequently shortly fell away to the condition of sand. Closer inspection revealed the fact that the blocks, when brought to the surface, were in a hydrated condition, giving forth a dull instead of clear, ringing sound when struck with a hammer, and showing a lusterless fracture, though otherwise unchanged. That such had not previously fallen away to the condition of sand, it is assumed, was due to the vise-like grasp of the surrounding rock-masses.

Solution.—It is, however, the solvent power of water that most concerns us here, though solution alone plays a comparatively unimportant part upon rocks not first subjected to physical and oxidizing agencies, excepting in the case of those composed essentially of carbonate of lime or magnesia. Rain and nearly all superficial waters as already noted contain traces of carbonic and other organic acids,[1] which act upon the material of the rocks, carrying it away invisibly, but none the less surely.

As long ago as 1848 the Rogers brothers showed[2] that pure water partially decomposed nearly all the ordinary silicate minerals which form any appreciable part of our rocks. The action of carbonated water upon the minerals in a finely pulverized condition was recognizable in less than ten minutes, but pure water required a much longer time before its effect was sufficient for a qualitative determination. So pronounced was the action

[1] Under this head are included the complex, unstable and little understood products of plant decomposition known as humic, ulmic, crenic and apocrenic acids. These act not merely as reducing agents (from their tendency to themselves undergo oxidation) but are energetic solvents as well, attacking not merely the lime carbonates but also silica and phosphates, arsenates and sulphates of the alkaline earths and the metallic sulphides.

BERTHELOT and ANDRE (Comptes Rendus Academie de Paris, 114, 1892, pp. 41–43) have shown that the brown substance of humus and analogous compounds undergo direct oxidation under the influence of the air and sunlight, forming carbonic acid. These reactions are purely chemical, taking place without the intervention of microbes, and are accompanied by a change in color of the original humus. The oxidation is rendered more active through the division and mellowing of the humus by cultivation. Through chemical union of the carbonic acid with certain bases, as lime soda and potash there are formed soluble carbonates which may be leached out by meteoric waters.

[2] American Journal of Science, Vol. V, 1848.

that the presence of the alkalies of lime and magnesia could be recognized in a single drop of the filtrate from the liquid in which the powdered minerals were digested. By digestion for forty-eight hours in carbonated waters they obtained from hornblende, actinolite, epidote, chlorite, serpentine, feldspar, etc., a quantity of lime, magnesia, oxide of iron, alumina, silica and alkalies amounting to from 0.4 to 1 per cent. of the whole mass. The lime, magnesia and alkalies were obtained in the form of carbonates ; the iron, in the case of hornblende, epidote, etc., passing from the state of carbonate to that of peroxide during the evaporation of the solutions. Forty grains of finely pulverized hornblende, digested for 48 hours in carbonated water at a temperature of 60°, with repeated agitation yielded : silica 0.08 per cent.; oxide of iron 0.095 per cent.; lime 0.13 per cent.; and magnesia 0.095 per cent. with traces of manganese. Commenting on these results Bischof remarks[1] that "by repeating this treatment 112 times with fresh carbonated water, a perfect solution might be affected in 224 days." If now he says, "40 grains of hornblende unpowdered, in which, according to the above assumption, the surface is only $\frac{1}{1000000}$ of the powdered, were treated in the same way, and the water renewed every two days, the time required for perfect solution would be somewhat more than six million years." In considering these figures and their practical bearing we must remember that while in nature the quantity of water coming in contact with a crystal imbedded in a rock during a given time is much less than that assumed above, the mineral is undergoing a gradual splitting up, becoming more and more porous, so that the process is gradually accelerated.

Richard Müller has also shown[2] that carbonic acid waters will act even during so brief a period as seven weeks upon the silicate minerals with such energy as to permit a quantitative determination of the dissolved materials. The accompanying

[1] Chemical and Physical Geology, Vol. I, p. 61.

[2] Untersuchen über die Einwirkung des kohlensaurehaltigen wasser auf einige Mineralien und Gesteine. Tschermaks Min. Mittheilungen. 1877, p. 25.

table shows (1) the percentages of the various constituents thus taken out by the carbonated water and (2) the total percentages of the materials dissolved. That is to say, the figures 0.1552 given for adular under SiO_2, indicate that 0.1552 per cent. of the total 65.24 per cent. of the silica contained by the mineral has been removed, and so on. The last column, on the other hand, gives the total per cent. of the entire rock of all the constituents extracted.

Mineral	SiO_2	Al_2O_3	K_2O	Na_2O	MgO	CaO	P_2O_5	FeO	Total
Adular......	0.1552	0.1368	....	....	.. .	....	....	trace	0.328
Oligoclase...	0.237	9.1713	....	2.367	....	3.213	....	"	0.533
Hornblende .	0.419	trace	....	....	....	8.528	....	4.829	1.536
Magnetite ...	trace	.....	....	....	....	....	....	0.942	0.307
Apatite	.....	.....	....	....	....	2.168	1.822	.....	2.018
Olivine	0.873	trace	....	....	1.291	trace	....	8.733	2.111
Serpentine ..	0.354	.....	....	....	2.649	....	....	1.527	1.211

The summary of his investigation is given as below:

(1) All the minerals tested were acted upon by the carbonated water.

(2) In this process there were formed carbonates of lime, iron, manganese, cobalt, nickel, potash and soda.

(3) In the action of the carbonated waters upon the alkaline silicates like the feldspars, a small amount of silica went always into solution, presumably in the form of hydrate.

(4) Even alumina was dissolved in appreciable quantities.

(5) Adular proved more resisting to the action of the acid than did oligoclase.

(6) The first stage of decomposition in the feldspars was a reddening process; the second, kaolinization.

(7) Hornblende was more easily decomposed than feldspar.

(8) Increase of pressure on the solution was productive of more energetic action than prolonging the time.

(9) Of all the minerals tested, the magnetic iron was least affected.

(10) Apatite was readily acted upon, as could be detected by its appearance under the microscope.

(11) Olivine was the most readily attacked of all the silicates tested, probably twice as easily decomposed as the serpentine.

(12) Magnesian silicates were attacked by the carbonated waters. Hence serpentine cannot be considered a final product of decomposition.[1]

Of all the materials forming any essential part of the earth's crust the limestones are most effected by the solvent power of water. It is stated that pure water will dissolve one part in 10,800 when cold and one part in 8.875 when boiling of lime carbonate.

Since rock weathering is, as already stated, a superficial phenomenon, we have to do only with waters of ordinary temperatures and under ordinary conditions of pressure though this expression must not be taken as necessarily meaning *cold* waters, since during the rainy season in tropical countries the waters falling upon the heated rocks may have their temperatures raised as high as 140° F. or even 150° according to A. Caldeleugh.[2]

It is almost wholly to this solvent action that is due the formation of the multitudinous caverns of limestone regions. Even where caverns are not apparent the corrosive action is evident to the practiced eye. In the quarry regions of Tennessee surface blocks of limestone are often grooved to a depth of an inch or more with wonderful sharpness, simply from the water of rainfalls with its acids absorbed from the atmosphere and surface soils, while in the quarry bed the stone is found no longer in continuous layers, but in disconnected bowlder-like masses. In such cases casual examinations give very little clue to the rapidity of the destruction going steadily on, since all is removed in solution excepting the comparatively small amount

[1] Serpentine, however, cannot be properly considered a decomposition product. It is rather a product of *alteration*.

[2] On the Geology of Rio Janeiro, Trans. Geol. Soc. of London, 2d Ser. Vol. II, 1829.

of insoluble matter (usually clay or silica) existing as an impurity. In these limestone regions the solvent action has not infrequently gone on so extensively as to leave its imprint upon the topographic features of the landscape. The drainage is no longer wholly superficial but by subterranean streams sinking entirely into the ground to reappear again at lower levels, it may be miles away, having traversed the intervening distance in some of the numerous passages (fissures enlarged by solution) with which the rocks abound. Entire landscapes are not infrequently undulating through the abundance of sinkholes—shallow depressions down through which the water has percolated and escaped into the underground passages. An idea of the amount of material thus dissolved may be gained when I state that some 275 tons have been calculated[1] as annually removed from each square mile of Calciferous (Lower Silurian) limestone exposed in the Appalachian region alone, while a well-known English authority[2] has calculated that with an annual rainfall of 32 inches percolating only to a depth of 18.3 inches, there are annually removed by solution from the superficial portions of England and Wales an average of 143.5 tons per square mile of area. He further calculates that the average amount of carbonate of lime alone annually removed from each square mile of the entire globe amounts to 50 tons. It is to this corrosive action of meteoric waters that still another authority[3] would attribute the slight thickness and nodular condition of many beds of Palæozoic limestone. He argues that originally thick bedded limestones have, during the ages subsequent to their formation and uplifting become so impoverished through the dissolving out and carrying away in solution of the lime carbonate, as to have been quite obliterated or reduced to mere nodular bands, and given rise to important palæontological breaks in the geological record. Other than organic acids may locally exert a potent influence.

[1] A. L. Ewing, Am. Jour. of Science, 1885, p. 29.

[2] T. Mellard Reade (Chemical Denundation in Relation to Geological Time).

[3] F. Rutley, the Dwindling and Disappearance of Limestones, Quar. Jour. Geol. Soc. of London, Aug. 1893.

Thus Robert Bell has described the dolomitic limestones underlying the waters along Grand Manitou Island, the Indian peninsula and adjacent portions of Lake Huron and the Georgian Bay, as pitted and honeycombed in a very peculiar and striking manner. This corrosion, it is believed is, produced through the solvent action of sulphuric acid in the water, the acid itself arising from the decomposition of the sulphides of iron pyrites and pyrrhotite, which exist in great quantities in the Huronian rocks to the northward.[1]

George P. Merrill.

[1] Bull. Geol. Soc. of America, Vol. VI, p. 47–304.

(To be continued.)

EDITORIAL.

THAT law of rhythm which pervades the inanimate world seems also to preside over the incoming and outgoing of intellectual stages and commanding personalities. Just prior to the middle of this century there arose a group of geologists of peculiar ability, and for five decades or more they have wielded a most powerful influence in reshaping the doctrines of the science which had been transmitted in relative immaturity from the earlier fathers. For the past two decades they have taken the place of these older masters as the recognized fathers of geology. But we are now called upon to note that the ebb of the rhythm, happily so long delayed, has of late been setting sadly out. The inevitable evening tide of life that so lately bore Dana away has, within the past four months, carried away Daubrée, Pestwich, Whitney and Green, all eminent, if not preeminent, in their special fields. The first three had filled out more than the usual span of active life, eighty-two, eighty-four and seventy-six years respectively, while the last had reached the ripe maturity of sixty-four years. Daubrée was best known for his "*Études Synthétique de Géologie Expérimentale;*" Prestwich for his "*Geology, Chemical, Physical and Stratigraphical;*" Whitney for his "*Metallic Wealth of the United States,*" and Green for his "*Physical Geology;*" though these are but the more conspicuous among their many important treatises. Works and names like these give deep inspiration to those whose careers are yet opening before them, and upon whom it falls to swell the incoming tide that must replace, so far as it may, the outgoing one.

T. C. C.

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A UNIQUE feature of the meeting of the geological section of the American Association for the Advancement of Science was

the commemoration of the sixtieth anniversary of the great work of Professor Hall on the geology and palæontology of the state of New York. Six decades of continuous service, and that, *nota bene*, official service, with a hopeful outlook on the seventh, is indeed a rare record. No work has been equally influential in the correlation of the palæozoic terranes of America, and none is more worthy of the special honors so appropriately and so happily bestowed.

The synopsis of the papers given in *Science* indicates a programme of much variety and value. The scientific interest seems to have reached its climax in the discussions of Mr. Gilbert bearing upon the history of Niagara Falls, and in the excursion connected therewith. The announcement of a third postglacial outlet for the upper lakes is a matter of wide historical importance. The following is a list of the papers offered:

"Notes on the Artesian Well sunk at Key West, Florida, in 1895." By Edmund Otis Hovey.

"The Hydraulic Gradient of the Main Artesian Basin of the Northwest." By J. E. Todd.

"The True Tuff-beds of the Trias, and the mud enclosures, the underrolling, and the basic pitchstone of the Triassic Traps." By B. K. Emerson.

"Volcanic Ash from the North Shore of Lake Superior." By N. H. Winchell and U. S. Grant.

"The 'Augen-gneiss,' Pegmatite Veins, and Diorite Dikes at Bedford, Westchester Co., N. Y." By Lea McI. Luquer and Heinrich Ries.

"The Tyringham (Mass.) 'Mortise Rock,' and Pseudomorphs of Quartz after Albite." By B. K. Emerson.

"The Succession of the Fossil Faunas in the Hamilton group at Eighteen Mile Creek, N. Y." By Amadeus W. Grabau.

"Development of the Physiography of California; Synopsis of California Stratigraphy." By James Perrin Smith.

"Ancient and Modern Sharks, and the Evolution of the Class." By E. W. Claypole.

"Observations on the Dorsal Shields in the Dinichthyids." By Charles R. Eastman.

"The Discovery of a new Fish Fauna, from the Devonian Rocks of Western New York." By F. K. Mixer.

"Notes on certain Fossil Plants from the Carboniferous of Iowa." By Thomas H. Macbride.

"Interglacial change of course, with gorge erosion, of the St. Croix River, in Minnesota and Wisconsin; The Cuyahoga Preglacial Gorge in Cleveland, Ohio." By Warren Upham.

"A Revision of the Moraines of Minnesota." By J. E. Todd.

"Origin of the High Terrace Deposits of the Monongahela River." By I. C. White.

"The Making of Mammoth Cave." By Horace C. Hovey.

"The Colossal Cavern." By Horace C. Hovey.

"James Hall, Founder of American Stratigraphic Geology." By W J. McGee.

"Professor Hall and the Survey of the Fourth District." By John M. Clarke.

"Sheetflood Erosion." By W J McGee.

"Glacial Flood Deposits in the Chenango Valley." By Albert P. Brigham.

"Origin of Conglomerates." By T. C. Hopkins.

"Origin of Topographic Features in North Carolina." By Collier Cobb.

"The Cretaceous Clay Marl Exposure at Cliffwood, N. J." By Arthur Hollick.

"Post-Cretaceous Grade-Plains in Southern New England." By F. P. Gulliver.

"The Algonquin River." By G. K. Gilbert.

"The Whirlpool-Saint David's Channel." By G. K. Gilbert.

"Profile of the bed of the Niagara in its Gorge." By G. K. Gilbert.

"The Niagara Falls Gorge." By George W. Holley.

"Origin and Age of the Laurentian Lakes and of Niagara Falls." By Warren Upham.

"Correlation of Warren Beaches with Moraines and Outlets in Southeastern Michigan." By F. B. Taylor.

"Notes on the Glacial Succession in Eastern Michigan." By F. B. Taylor.

"The Operations of the Geological Survey of the State of New York." By James Hall.

"The Eocene Stages of Georgia." By Gilbert D. Harris.

"The Origin and Age of the Gypsum Deposits of Kansas." By G. P. Grimsley.

"Geomorphic Notes on Norway." By J. W. Spencer.

"The Slopes of the Drowned Antillean Valleys." By J. W. Spencer.

"Notes on Kansan Drift in Pennsylvania." By E. H. Williams.

"Preliminary Notes on the Columbian Deposits of the Susquehanna." By H. B. Bashore.

"Pre-Cambrian Base-leveling in the Northwestern States." By C. W. Hall.

The monograph on the North American Camerata by Wachsmuth and Springer, which was reviewed by Charles R. Keyes in the February-March number of the Journal, has not yet been issued and we are informed that it will not probably appear before the close of the year. It is perhaps unnecessary to say that the review was accepted without so much as a question as to the fact of the issuance of the work, and we are assured by the reviewer that he had no doubt, from his understanding with the lamented senior author, of its appearance before the publication of the review. Our common apologies are due for the premature notice, which are only relieved by the reflection that the review was an expression of warm admiration of the work and of a desire to give it a prompt and most cordial recognition. It is due to Mr. Bather, the eminent English student of the Crinoidea, to whose views adverse illusion was made on a certain point, to ask a suspension of judgment on the matter in question until the work shall be read. T. C. C.

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The current season is proving exceptionally fruitful in Arctic exploration. The results of Nansen's most remarkable voyage have much scientific significance, especially his discovery of a deep sea stretching as far east as 133° longitude and as far south as 78° latitude. This, with its attendant phenomena, forms a very important contribution to the general configuration of the crust in the north polar region. Nansen has our warmest felicitations, as he has had all along our fullest sympathy.

The safe return of the gallant Peary with the scientific parties from Cornell University and the Massachusetts Institute of Technology is also a matter of congratulation. Although unsuccessful in bringing away the great meteorite, they have undoubtedly gathered much valuable data regarding the ethnology and geology of North Greenland. The results of the glacial studies and of the pendulum observations will be awaited with special interest. T. C. C.

Reviews.

Great Valley of California; a Criticism of the Theory of Isostasy, by F. LESLIE RANSOME: Univ. California, Bull. Geol. Dept., Vol. I, pp. 371–428, 1896.

British Geology, by T. MELLARD READE: Geological Magazine, Dec. 4, Vol. II, pp. 557–565, 1895.

Notes on the Gravity Determinations Reported by Mr. G. R. Putnam, by GROVE KARL GILBERT: Bull. Philos. Soc. Washington, Vol. XIII, pp. 61–76, 1895.

Three papers have been issued recently which have a direct bearing upon the theory of isostasy. Two are of the nature of criticisms; one being the outcome of studies conducted in this country, and the other of inquiries instituted in England. The third introduces some new complications which the advocates of the hypothesis would hardly expect.

The first memoir is of more than ordinary interest in being an attempt to practically test the theory from a purely geological standpoint, and to apply the principles to a particular limited region unusually favorably situated for obtaining tangible results. The paper had its origin in a review of the literature bearing upon the theory of "conservation of equilibrium in the earth's external form, which Dutton has named Isostasy, and which has come into prominence mainly through the labors of that illustrious group of American geologists to whom geology is so deeply indebted for certain broad views and far-sighted generalizations, which in spirit and expression recall the wide regions and clear atmosphere in which the authors worked."

Accordingly the discussion is appropriately subdivided into five distinct parts, (1) a description of the Great Valley as it is today, (2) an outline of the geological evolution through which it has arrived at its present form, (3) an account of the development of the so-called "doctrine of isostasy" as a working hypothesis, (4) a discussion of the applicability of this hypothesis to the Great Valley, and (5) a more

general discussion of the theory of isostasy, with illustrations drawn from other regions of elevation or subsidence.

Before all, the physiographic features of the Great Valley are fully considered and the several parts in some detail. The main geological features are described and the evidence of several deep wells is brought in to show the composition of the strata underlying the region.

The geological history of the region is briefly and concisely related. This leads directly to the main theme—the principles of isostasy, for the Great Valley has an area in which there has been profound and progressive subsidence accompanied by great deposition. The literature relating to the theory is compactly brought together and summarized. The theory is then examined in the light of the facts derived from a study of the particular area.

The Great Valley represents a limited area in which 2000 feet of sediments were deposited at the same time that the rim was being raised. In explanation of the attendant phenomena the hypothesis of isostasy is not only regarded as unnecessary, but the facts presented are thought to directly oppose the idea of isostatic subsidence. A consideration of the essential features of isostasy shows it to be merely an hypothesis of readjustment and not of initial movement. It can operate only after conditions have become unstable. So far as applied to the Great Valley it is shown conclusively that the orogenic movements elevating the Coast Range began before the "formation of the valley and are consequently independent of any loading and subsidence." A little latter the Sierra Nevada range began to rise and in the great syncline between were deposited shallow water sediments to a depth of 2000 feet. Other facts are enumerated that are believed to be opposed to the hypothesis of isostatic movement in the valley. Several Californian areas are also brought in as presenting phenomena perfectly inexplicable upon the isostatic principle. After passing them the general discussion of the theory as a whole is reached.

In discussing the data upon which the theory has been made to rest specific cases are taken up. McGee's consideration of the Gulf of Mexico and the great Mississippi embayment receive particular attention. It is not, however, with the acumen shown in the other parts of the memoir. Some of the very objections urged against the region having subsided by loading are themselves so manifestly defective that they have the very opposite effect from that intended and naturally strengthen the hypothesis rather than weaken it. One point in partic-

ular may be noted: "The Mississippi River, during later geological times, has pushed its delta from Cairo out to its present termination in the Gulf of Mexico, an extension that is not compatible with the idea of *pari passu* local sinking under load, but which indicates a subsidence of more general extent, and independent of such local loading, inasmuch as the maximum effect has been, not near Cairo, at the original point of loading, but to the south of it—probably in the deep hollows of the present Gulf of Mexico. The river did not stop to build up a thick mass of delta accumulations at Cairo, as it should have done according to the theory of isostasy; but, attracted onward by the independent subsidence to the south it has covered the floor of the valley with relatively thin deposits only, and advanced persistently out into the Gulf."

Now the real reason that the Mississippi River did not build up a thick mass of delta accumulations at the head of the present embayment, "as it should have done according to the theory of isostasy" is that Cairo is probably not only not "the original point of loading," but the latter point is to the south of it, far to the south, in fact nearly as far as New Orleans. This is at once apparent from a glance at the history of the region. At the close of the Cretaceous or early in the Tertiary the whole region was a vast graded surface, or peneplain, the southern limit of which was as far south at least as central Louisiana. The present Mississippi River was a comparative insignificant stream with none of its present tributaries beyond the present city of St. Louis. The peneplain is found on the east side of the embayment dipping westward and on the west side dipping eastward under the unconsolidated clastics of the embayment, thus forming a broad shallow syncline, as recently shown by Griswold. The warping which has taken place since the beginning of this down-sinking along the line of the Mississippi has allowed a relatively thin mantle of later sediments to be deposited over a large area. While at various times the waters of a shallow sea may have been extended over a considerable portion of the embayment "the original point of loading" was doubtless not so very far from where it should be, nor is the present point of maximum depression and maximum loading far from "where it should be according to the theory of isostasy." This, it may be added introduces factors that are not commonly taken into account in the consideration of the genesis of large deltas.

Most of the other objections to the hypothesis of isostasy are well formulated and some of them appear unsurmountable.

In conclusion the author says: "The considerations presented in the foregoing paper indicate that, while the greater inequalities of the earth's surface, such as the continental arches and the oceanic depressions, may exist by reason of isostasy, the mass of available evidence is opposed to the view that denudation and sedimentation are able to produce movements in the earth's crust, as direct consequences of the weight of the material shifted. Not only do such superficial processes seem inadequate to initiate deep-seated crustal movements, but, as far as we can see, the movements, even when initiated through other causes, are as indifferent to such processes as is a slumbering volcano to the changes wrought by human tillage upon its flanks."

Mr. Reade's most recent references to the hypothesis of isostasy are contained in the presidential address to the Liverpool Geological Society in which he describes briefly the geology of the British Isles in relation to mountain building. The allusions to isostasy are incidental rather than specific and the conclusions to be deduced are against the theory. In this connection he gives a summary of his latest opinions regarding the cause of orogenic movements and ascribes them entirely to changes of temperature, producing expansion and contraction, and not to the shrinkage of the nucleus of the earth, the closing in of the non-shrinking crust upon it and the consequent folding by tangential pressure. In concluding he says: that "Neither does the principle of isostasy so insisted upon by American geologists explain the compression, folding and building up of great masses of sediment into mountain ranges. On the principle of isostasy, it must be obvious to anyone possessing even a rudimentary acquaintance with mechanics that the sinking of the bed of the seas on which great deposits are accumulating, and to some extent a rise of surrounding land, may be explained, but not the lateral compression and elevation of the sediments themselves into mountain ranges."

Mr. Gilbert's notes are of great interest at this time. They are based upon a series of trans-continental gravity determinations made by Mr. G. R. Putnam, and are appended to the latter's article. As generally understood isostasy is intended to cover those oscillations which are the direct result of local or provincial loading and unloading. This appears to be the specific limitation placed upon the hypothesis by Messrs. Dutton and McGee. Mr. Gilbert, however, uses the term

in the present case in the broadest sense. He starts out by postulating general isostasy thus making the term nearly equivalent to a universal static conservation. His theme is stated as follows: "Let us postulate that the greatest features of the earth's relief, such as continents and great plateaus, are sustained isostatically, and that the small features, such as hills and small mountains, are within the competence of terrestrial rigidity, and then let us inquire what the pendulum work of the Coast Survey has to tell of the status of features of intermediate size, namely the greater mountains and smaller plateaus."

After describing the methods followed in making the determinations the details of the various stations at which pendulum measurements were made are discussed. Although the results of the calculations deviate greatly from what would be expected according to the hypothesis of isostasy the measurements are found to be "six times as discordant from the point of view of rigidity as they are from the point of view of isostasy."

In conclusion it is stated that the "measurements of gravity appear far more harmonious when the method of reduction postulates isostasy than when it postulates high rigidity. Nearly all the local peculiarities of gravity admit of simple and rational explanation on the theory that the continent as a whole is approximately isostatic, and that the interior plain is almost perfectly isostatic. Most of the deviations from the normal arise from excess of matter and are associated with uplift. The Appalachian and Rocky Mountains and the Wasatch plateau all appear to be of the nature of added loads, the whole mass above the neighboring plains being rigidly upheld. The Colorado plateau province seems to have an excess of matter, and the Desert Range province may also be overloaded. The fact that the six stations from Pike's Peak to Salt Lake City, covering a distance of 375 miles, show an average excess of 1345 rock-feet indicates greater sustaining power than is ordinarily ascribed to the lithosphere by the advocates of isostasy."

CHARLES R. KEYES.

Text-Book of Palæontology. Vol. I., Part 1. By KARL A. VON ZITTEL. Translated and edited by CHARLES R. EASTMAN, PH.D. London: Macmillan & Co., Ltd., 1896.

An English edition of von Zittel's *Paläontologie* is the most welcome of palæontological works that has appeared in a long time. The

original edition while largely used in this country did not, on account of being in a foreign language, meet all the wants of American students, particularly the younger ones. No department of science has been more in need of a good English text-book than palæontology. Educators in general will owe to Dr. Eastman a deep debt of gratitude for providing our colleges and higher schools with a "translated, revised and enlarged edition" of the best manual on palæontology that has ever been written. Professor von Zittel is to be congratulated not only for the improvement presented by his new text-book, but also, as shown by the results, for having entrusted the preparation of the translated edition to such excellent hands.

To one accustomed only to the standard English works on palæontology, or even to the majority of foreign ones, the style and mode of treatment adopted by the author must seem a welcome innovation. The plan on which it is written is in fact original with Professor von Zittel, and was first adopted by him in the larger work, for which he is famous, the *Handbuch der Paläontologie.* It may be regarded as the best method yet devised for treating, in one and the same book, not only the main facts of the science as viewed from the biological side, but also systematic palæontology. Authors of zoölogical text-books are confronted with the same difficulty, how to relegate to the systematic and the general part each its due share of attention, without confusing the student nor presupposing for him too much technical knowledge. The great success of von Zittel's method has been demonstrated during the twenty years his larger treatise has been in use, and justifies its extension to an elementary work.

Another feature which the present text-book shares in common with the *Handbuch* is its richness of illustration. Its figures are necessary to the advanced student, and everyone knows for himself how dependent he is on good figures for an understanding of new forms; how much more essential is it that the beginner be supplied with an abundance of illustration. Perhaps in no department of science is the need of pictorial representation so great as in palæontology, owing to the fragmentary or distorted condition of the bulk of the fossil material. The German edition, which comprises 950 pages, is provided with 2500 woodcuts; the translation promises to increase this number to upwards of 3000. Part 1, which forms the immediate subject of this notice, has fifty-five illustrations more than the corresponding portion of the original. Great discretion has been exercised to select typical

forms for representation, and in the case of diagrams or restorations, pains have been taken to emphasize the more salient features. In some cases, hypothetical restorations that have been since proved to be faulty are altogether discarded, or in other cases are replaced by more perfect ones. In fact, the aim has been to make the pictorial or visualized part not less intelligible and truthful than the descriptive.

As to the subject-matter, the arrangement and coördination is on the whole philosophical and well balanced. In a work of this kind, the relative importance to the palæontologist must be the criterion which governs the amount of space devoted to each group. Hence certain groups which to the zoölogist are of but slight interest are necessarily treated in considerable detail in a palæontologist's manual, and on the other hand numerous subdivisions are passed over unnoticed in the latter, which occupy an important place in zoölogical text-books. In the original, the allotment of space was determined for each class by the author, but in the translation the same ratio has not been preserved, owing to variations in the amount of additional matter contributed by the different collaborations. The result is that some sections have been treated with greater thoroughness than others, but the fault, if it be one, is rather to be commended than condemned. That is, it is better that certain groups receive the painstaking revision of an acknowledged expert, as in the case of the Echinoderms, Bryozoans, or Brachiopods, than that the character of the work as a whole be elevated only a little above the high standard laid down in the original.

This brings us to speak more particularly of the nature of the revision which the English translation has undergone, and also of the classification employed. It was originally intended to bring out a strictly literal translation of von Zittel's *Grundzüge der Paläontologie*, which should follow closely the new German edition. But palæontology is not a fixed science, and fresh discoveries are constantly causing changes and improvements in every system. Hence, to be abreast of the times, a text-book must include the results of the latest authenticated observations, and this can only be done nowadays by enlisting the aid of a body of investigators scattered over the entire field of science. It is to the lasting credit of Professor von Zittel, be it said, that he consented to an arrangement whereby portions of his newly completed treatise were parceled out to a dozen or more specialists for detailed revision and enlargement; and it also speaks

well for the energy of Dr. Eastman in enlisting the sympathy and assistance of the men best fitted for the undertaking. It certainly must require unbounded magnanimity for an acknowledged master of the science to see a work of his, scarcely dry from the press, passing into the hands of different men for the sole purpose of picking it to pieces and building it up again; to see the introduction of a different terminology, or worse still, a classification different from his own; and finally to see the names of other authors appearing at the close of the several chapters, each being awarded a portion of the credit for the excellence of the work. Doubtless all this was not accomplished without a struggle, for it is hard for any one who has long been accustomed to familiar names or systems, to see them encroached upon or entirely replaced by others. It may be questioned whether Continental workers are entirely in sympathy with the younger American school of palæontologists; yet it is clear that so great an author as Karl von Zittel has confidence in their methods, or he would hardly have permitted such changes to be made in his book. His attitude toward this school may also be gathered from a remarkable address before the International Congress of Geologists, reprinted in a late number of the *American Geologist.* We must certainly regard him not only as one of the ablest but as one of the most progressive of modern palæontologists.

To comment briefly upon the various chapters we note first that the Introduction is condensed into sixteen pages, in which the main principles of the science are expounded. The next twenty-five pages are devoted to the Protozoa, Brady's system having been followed in the main for the Foraminifera and Haeckel's for the Radiolaria. The treatment of the sponges, which also occupies twenty-five pages, betrays a master hand. The classification put forward by the author in the *Handbuch*, remains today, with a few unimportant modifications, the best that has been devised. The chief criticism that may be urged against this section is the adoption of too many needless terms proposed by Rauff; the figures and descriptions, however, are of their usual excellence, and the same is true of the corals. The author has been very conservative in his handling of both the Anthozoa and Hydrozoa. It would have been well had a greater notice been taken of American forms, and a more natural classification adopted. It is evident that pages 103–5 are to be considered as replaced by the more extended treatment of the same forms under the Bryozoa, and their double insertion may be overlooked in consequence. It is to be

regretted also that the graptolites were not more extensively described, although abundant references to the literature are supplied at the end of the chapter.

Coming to the Echinoderms, which occupy 125 pages, we note the first great innovation, as nearly the whole section has been fundamentally revised and enlarged. The late eminent crinologist, Mr. Charles Wachsmuth, is mainly responsible for the condition of the Crinoids and Blastoids, valuable notes, however, having also been supplied by Mr. F. A. Bather and Dr. Otto Jaekel. The Ophiuroids and Asteroids were put in their present excellent condition by Mr. Percy Sladen, vice president of the Linnean Society, and to the same high authority credit is due for having revised the entire Echinoid chapter in accordance with the latest approved classification. Some notes on the Worms were contributed by Dr. G. J. Hinde, but this section is not appreciably extended.

The subkingdom Molluscoidea is the next to claim our attention. The chapter on Bryozoans has been entirely rewritten and greatly extended by Mr. E. O. Ulrich. Such a detailed treatment as this part presents would have been more appropriate for a handbook of palæontology than for an elementary treatise, but the unusually large amount of space devoted to the group is excusable perhaps on account of the absence of a correspondingly larger work to which students may refer. Nevertheless we are fortunate in having an extended account of this difficult group made so accessible.

The chapter on the Brachiopods may be regarded as the latest and highest authority for our knowledge on the subject. It has been very skillfully drawn up by Mr. Charles Schuchert, of the U. S. National Museum, and has received some additional illustrations from the writings of Professor C. E. Beecher. The classification adopted is that employed by Mr. Schuchert in his excellent "Synopsis of American Fossil Brachiopoda," and represents an extension of the system originated by Professor Beecher. Every known genus of Brachiopods, fossil and recent, finds notice here, and the condensation is marvelous. The work could have been amplified to almost any desired extent, but it could hardly have been more complete, concise, and clear. It goes without saying that the synonymy indicated is approved by the leading authorities on this group. Considering the scope and nature of the text-book it is difficult to see how this chapter could have been very materially improved.

Only the introduction to the Pelecypods is contained in Part 1, but its improvement over the original is manifest, and we are able to form some idea of what may be expected from Dr. Dall, on this group and the Gastropods. The appearance of the concluding part of the first volume will be awaited with great interest, since without doubt the contributions of Messrs. Hyatt, Beecher, Clarke, Scudder, and others who are understood to be engaged on its revision will so elevate the character of the work as to render it the standard authority on the subject for years to come.

Palæontological science is certainly beholden to Wachsmuth, Sladen, Ulrich, Schuchert, Dall, and the others for their labors of love in trying to make this an authoritative and trustworthy text-book. How well they have succeeded remains to be determined after the book has been used in the laboratory, and it is certainly to have a wide use here. The improvement is so marked over the German edition, the "translation" contains so little from the original, and the "revision" is so complete that the question naturally arises whether Dr. Eastman could not just as well have gone a little farther in his work and made it a text-book by American authors which would have held the same place among English-speaking people as the original *Handbuch* does among the Europeans.

CHARLES R. KEYES.

Die Eruptivgesteine des Kristianiagebietes. II. Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol. By PROFESSOR W. C. BRÖGGER. Pp. 1–183, with 19 figures in the text. Kristiania, 1895.

For the purpose of gaining more light upon certain eruptive relationships of the rocks of the Christiania region, Professor Brögger and his friend Professor Ussing spent eight days in studying this classic locality of the south Tyrol. In a delightful introduction some idea is given of the perennial interest of the region to geologists by reference to the long roll of the most famous workers in geology preserved in the old guest-book of the "Golden Ship" at Predazzo.

The name *monzonite* (from the village of Monzoni) was first applied to the eruptive rocks of this region by Lapparent in 1864, but since his time different authors have used it in various senses. The earlier writers usually referred to these rocks as syenites. Tschermak in 1869

defined monzonite as a peculiar rock varying between syenite and diorite as extremes. His name was for a *geological* unit, however, and was not a petrographic definition. Dölter in 1875 adopted a similar usage; hand specimens of monzonite were syenite, diorite, gabbro, augitfels, or diabase. Rosenbusch, Teall, and Zirkel refer to monzonite as augite syenite. Nearly all writers have agreed in regarding the rocks of this locality as a series of intimately related members, ranging from acid to basic chemical composition, but have differed as to which is the main type.

In the laboratory the author's collection of specimens was found to fall into two groups — an acid group with 50–60 per cent. of silica, and a basic group with less than 50 per cent. of silica. The former group is the main one and embraces the monzonites proper, which are orthoclase-plagioclase rocks; while the latter are pyroxenites, and are merely peripheral facies of the monzonite, into which they grade. The term *monzonite* is thus given definite petrographic significance as the name of a transition or intermediate group of rocks between the orthoclase rocks (syenites) on the one hand, and the plagioclase rocks (diorites) on the other. The former method of uniting such a transition group with one or other of the limiting members of the series would, in this case, fail to express the most characteristic thing about these rocks, viz., that they contain plagioclase and orthoclase in about equal proportions.

Chemical investigation still further shows the need for a special name for the group. The probable range in silica percentage in all the monzonites is from 62–60 per cent. down to 50–48 per cent. This excludes all granites, quartz diorites, and quartz syenites from the comparison. The gabbros, too, are mostly more basic, have lower alkali contents, higher lime, and generally higher magnesia and iron oxides. A direct comparison, then, is necessary only with the syenites and diorites. The nepheline syenites have about the same silica contents as the monzonites, but are otherwise very different, as is shown by the following ratios deduced from thirteen analyses of nepheline syenites, and five of monzonites:

Nepheline syenite - -	$Ca:Na_2O:K_2O::1:4:2$
Monzonite - - -	$CaO:Na_2O:K_2O::10:4:3$

The chemical affinities of monzonite with the syenites and diorites are shown in the following table. All the analyses used for compari-

son were carefully chosen so as to secure typical and unaltered plutonic rocks.

	Potash Syenite	Soda Syenite	Monzonite	Diorite
SiO_2	60.57	58.32	55.88	56.52
TiO_2	.53	.54	not det.	.25
Al_2O_3	15.85	18.23	18.77	16.31
Fe_2O_3 (FeO, MnO)	8.23	7.16	8.20	11.09
MgO	2.59	1.31	2.01	4.32
CaO	4.44	4.12	7.00	6.94
Na_2O	2.13	5.70	3.17	3.43
K_2O	6.02	3.84	3.67	1.44
H_2O	1.06	1.02	1.25	1.03
P_2O_5	.58	.54	not det.	.40
	Mean of 3 Analyses	Mean of 10 Analyses	Mean of 5 Analyses	Mean of 16 Analyses

In the syenites the lime is low and the alkalies high ; in the diorites the lime is high and the alkalies low; in monzonite they are about equal. Study of the analyses shows that the monzonites form a chemically well-characterized "*Zwischengruppe*" between the syenites and diorites. They are true plutonic rocks of intermediate composition, with a medium lime percentage (6–7 per cent.), about the same amount of total alkalies, equally divided between potash and soda, high alumina (about 17–18 per cent.), and relatively low magnesia contents.

The structure of monzonite is that of a plutonic rock and is characterized by the fact that the orthoclase crystallized last in large allotriomorphic plates (*mesostasis*), partially enclosing the other minerals. The latter are plagioclase (usually labradorite or andesite) and augite. Olivine is abundantly present in certain basic members, but lacking in the more acid ones. Biotite, hypersthene, and hornblende occur sparingly. The accessory minerals are titanite, zircon, apatite, and iron ores.

Outside of the south Tyrol, rocks corresponding to monzonite have been described from Norway, Saxony, Schemnitz, Minnesota, and other parts of the world. An olivine monzonite occurs at Smälingen, while a rock from Rougstock, in the Bohemian Mittelgebirge, is a nepheline-bearing monzonite, and occupies a place between monzonite or augite diorite and theralite. The relations of monzonite to the syenites and diorites are graphically shown by a diagram. Monzonite occupies

the center of a triangle and by increase in soda passes through akerite and lavurikite to nepheline syenite; by increase of potash through plauenite and potash-feldspar-syenite to a hypothetical leucite syenite; and finally, by increase in lime, through alkali-rich diorite and alkali-poor diorite into an acid lime-rich norite, etc.

The pyroxenites of the region are basic peripheral facies of the normal monzonite. They were the first to solidify, as detached masses of pyroxenite are frequently included in the monzonite. The latter rock frequently shows porphyritic facies on its periphery, as is common in the Christiania region.

The monzonites and their peripheral facies are not the only eruptive rocks of Triassic age in this region. The complete series, and the sequence of eruption, is summed up by Brögger as follows:

(1) The oldest eruptions of Triassic time are represented by basic dikes and effusive rocks; melaphyre, augite-porphyrite, amygdaloids, tuffs, etc.

(2) Corresponding to the later eruptions of these basic dikes and effusive rocks, are also basic plutonic rocks (essentially pyroxenite, passing into gabbro-diabase, monzonite, etc.) of which relatively only insignificant masses are preserved as peripheral facies of more acid rocks.

(3) These more acid rocks, essentially monzonite, are of intermediate composition and belong to an independent rock-group within the series of the orthoclase-plagioclase rocks.

(4) Younger than the monzonites and the corresponding effusive rocks, are the red granites of Predazzo; also, probably, small veins of aplite and dikes of quartz porphyry.

(5) The youngest eruptions of the whole eruptive epoch are represented by an association of dikes; these are partly of ultra-basic composition, essentially camptonites, and partly of intermediate composition, commonly "liebeneritporphyre," or nepheline-bostonite. These two groups are related as complementary dikes. The bostonites appear generally to represent the youngest eruptions of the whole epoch.

Before applying the facts gained in the Tyrol to the study of the Christiania region, the author discusses the general laws governing the mechanism of eruption of plutonic rocks, and especially the hypothesis due to Kjerulf, Michel-Levy, and Suess, that the granites are batholithic, not laccolithic, and have displaced the invaded rocks by fusing and

assimilating them. He cites cases from the Christiania region where the granite has intruded the sedimentary beds in such a way that a portion of the latter has disappeared. The invading rock has metamorphosed the sediments, but the contact is sharp, and the granitite, which is normally very poor in lime, shows no chemical enrichment through "assimilation" of the calcareous beds with which it is in contact. During years of study, over magnificent exposures, in the Christiania region, Brögger has found no evidence in favor of any assimilation of the invaded sediments, nor for their "feldspathization" by the intruding magma. If the granite, then, has not absorbed the missing beds, where have they gone? They must, he says, be *underneath* the plutonic mass. "The plutonic rocks of the Christiania region have been brought into their present position by purely mechanical processes—by a squeezing up, and subsequent lateral intrusion, as a consequence of great subsidences of neighboring portions of the earth's crust. Their composition is not essentially influenced through assimilation of salbands, or through fusion of the overlying strata, but is the final result of differentiation processes of the original magma of the common magma-basin from which they all come. Their typical form is the '*Kuchenform*' of the laccolith." It is possible, however, that the Michel-Levy assimilation hypothesis and the Suess batholith hypothesis may apply to the great granite regions of the older "*Grundgebirge*" or to districts of folded, regionally metamorphosed rocks, but Brögger evidently considers it improbable.

The eruptive sequence of the Tyrolean region is compared with that of the Christiania region, and the facts are considered to support the view previously advanced by Brögger, that the differentiation sequence and the eruptive sequence are dependent upon the sequence of crystallization. The chemical composition of the hypothetical primary magma of the Austrian region is calculated by the method employed for the Christiania region in the preceding paper on the Grorudite-Tinguaite Series, and is found to have about the same silica percentage (65.2, as compared with 64.2 for the Christiania magma) but is rich in lime and poor in alkalies, while the Norwegian magma is poor in lime and rich in alkalies.

The paper concludes with some general considerations on the eruptive sequence of plutonic rocks. Such sequences are very difficult to work out in the field, and to be of service in determining the laws in accordance with which the differentiation processes have taken place

in a magma-basin, it is necessary to employ observations upon series of genetically connected eruptions, of a definitely bounded region, and belonging to a single eruptive period. The work of Iddings, Teall, Dakyns, and Wadsworth has shown that the *normal* series is basic — less basic — acid. This agrees with the explanation of differentiation through a diffusion toward the cooling surface of a magma-basin, which is regulated by the ordinary sequence of crystallization. According to Brögger the effusive rocks are in great part the products of a *secondary* differentiation from plutonic magmas; and, in general, the further away the magma-masses are from the original mother-magma, the more they have been subjected to secondary differentiation and the less regularity is observable in their eruptive sequence.

F. L. Ransome.

SUMMARY OF CURRENT PRE-CAMBRIAN NORTH AMERICAN LITERATURE.[1]

Gibson[2] gives a summary, from the reports of the Canadian Geological Survey, of the pre-Cambrian geology of the Hinterland of Ontario.

Coleman[3] gives a summary of the geology of the Rainy Lake region. Following Lawson, the rocks are classified as follows:

Archean	Upper division.	*a.*	Keewatin. (Huronian ?)
		b.	Coutchiching.
	Lower division.		Laurentian.

The Laurentian rocks consist chiefly of granite-gneisses, with subordinate quantities of granite and syenite. The Coutchiching consists of fine-grained mica-schists and mica-gneisses which show rapid changes in composition in passing from one layer to another, thus suggesting sedimentation. These rocks are usually sharply separated from the Laurentian, but at Rice Bay the writer found himself in doubt as to the classification. The Coutchiching series is regarded as a metamorphosed sedimentary one. As to the source of the material there is no very definite information, unless certain gneisses in Sand Island river having layers differing sharply in composition be looked upon as remnants of an original Laurentian floor. The Keewatin is a series of eruptive and fragmental rocks of great thickness and variety, consisting broadly of a lower division of basic eruptives and volcanic ashes, and an upper acid division. The bulk of the lower basic portion consists of diabases, with some gabbros and anorthosites, and apparently some diorites. Porphyroids are also present. The schistose members, often interbedded with the massive altered eruptives, near the contact with the

[1] Continued from p. 372, Vol. IV., Journal of Geology.

[2] The Hinterland of Ontario, by T. W. Gibson. Fourth Rept. Ontario Bureau of Mines, 1894, Sec. III, part on pp. 124, 125. Toronto, 1895.

[3] Gold in Ontario: Its Associated Rocks and Minerals, by A. P. Cole. Fourth Rept. Ontario Bureau of Mines, 1894, Sec. II, pp. 35–100. Accompanied by two geological maps of parts of the Rainy River district. Toronto, 1895.

Laurentian are chiefly hornblende-schists, but in other localities are chlorite-schists. Between these two are numerous transitions. Graywackes occur at several localities, and agglomerates and conglomerates are plentiful. The upper acid division includes felsites, sericite-schists, and quartz-porphyries. These are apparently younger than the green schists and massive rocks of the Keewatin, but the two divisions are conformable, as is also the whole of the Keewatin to the Coutchiching. The rocks included in the Laurentian are, for the most part at least, intrusive in the Coutchiching and Keewatin. In the Keewatin are various intrusive granite areas. Cutting all of the previous series are dike rocks, which may be divided into an acid division, including granite and pegmatite, and a basic division, including diabase and quartz-diabase.

Many details are given as to particular occurrences of the various rock series. The occurrence of gold in Ontario is described, and incidentally the rock succession in the Hastings district is summarized.

Winchell and Grant[1] give a preliminary account of the Rainy Lake gold region. Following Lawson, the rocks there found are separated into four distinct groups. Beginning with the lowest these are: (1) Laurentian, composed of granites and granitoid gneisses and allied rocks; (2) Coutchiching, composed of mica-schists grading into fine-grained gneisses; (3) Keewatin, composed of hornblendic, greenish, and sericitic schists, conglomerates, graywackes, etc.; (4) Diabase dikes, more recent than and cutting all the others. The Coutchiching mica-schists have in many places rapid alternations in bands from an inch to several feet in width of slightly different mineralogical composition, structure, or color. The position of these bands gives the strike and dip of the rock, and when they are lacking the schistose structure is taken as giving the strike and dip, as this seems to be parallel with the banding when the two are seen together. On account of basal conglomerate beds in places in the Keewatin resting on the Coutchiching, while an unconformity between the two is not proven, it seems quite probable.

COMMENTS.

The banding of the Coutchiching mica-schists in many places described by Coleman, Winchell, and Grant is just such as has been

[1] Preliminary Report on the Rainy Lake Gold Region, by H. V. WINCHELL and U. S. GRANT. 23d Ann. Rept. Geol. and Nat. Hist. Sur. of Minn., for 1894, Part II, 1895, pp. 36–105.

ascribed to igneous rocks in other localities, and it yet remains to be proved that the series is sedimentary. Even if sedimentary, no satisfactory evidence is given that either the schistosity or banding corresponds with bedding. Using the classification of the United States Geological Survey, the Keewatin or a part of it would be regarded as Huronian, and the Coutchiching or a part of it would be regarded as Archean. It is rather probable that in the Thunder Bay district of Ontario and in northeastern Minnesota parts of two series have been included under each of these terms.

Smyth and Finlay[1] describe the western part of the Vermilion range. The sedimentary rocks fall into two divisions. The older is a fragmental slate formation, while the younger is an iron-bearing formation lithologically identical with certain phases of the lower iron-bearing formation of the Marquette district. To all appearances it is devoid of clastic material. It is believed, from analogies with other iron-bearing districts of the Lake Superior region, that the jasper of the Vermilion district is derived from a cherty iron carbonate or from a glauconitic greensand, or both. However, as the jasper is a final product of the alterations, it is not possible to show this.

Intrusive igneous rocks are very abundant, cutting or being interleaved with the sedimentary rocks in masses running from the thickness of a knife blade to those 100 feet across. In quantity the igneous rocks exceed, perhaps several times the sedimentary rocks. The oldest igneous rocks are greenstones. These vary from massive to schistose, and into conglomerate-breccias. The acid rocks were intruded later than the basic rocks. They were originally for the most part quartz-porphyries, but these have been extensively changed to sericite-schists and conglomerate-breccias, and to rocks intermediate between these and the original form. Within the larger masses of the igneous rocks, both basic and acid, are frequently included fragments from both the slate and iron formations, from those of small size to masses more than 100 feet long.

The conglomerate-breccias are of dynamic origin. The first step in the development of the breccias was the formation of two intersecting sets of planes of fracture, dividing the originally massive rocks

[1] The Geological Structure of the Western Part of the Vermilion Range, Minn., by H. L. Smyth and J. Ralph Finlay. Trans. Am. Inst. of Min. Engineers, Vol. XXV, 1895, pp. 595–645.

into roughly rhomboidal blocks. Their further development depended on continued movement between these blocks under pressure, which resulted in enlarging the shearing zones at the surfaces of contact, and rounding the angles. The slate and jasper inclusions originally plucked off from the rocks which the porphyries and greenstones invaded, shared, of course, the subsequent history of their captors. The fact that the jasper inclusions are frequently rounded, while those of slate are not, is explained by the difference in the elasticity of the two rocks. The slate inclusions readily yielded and finally took a permanent set under the deforming forces, while the harder and more rigid jasper, in fragments of limited size and diverse orientation, behaved like the enclosing porphyry. The boundaries of the inclusions were generally the surfaces along which rupture took place, although, as has already been said, jasper in a few instances is found partly held in porphyry inclusions.

As to structure, the main slate area is anticlinal; both north and south of this area the jasper succeeds the slates. The southern jasper continues in a complex syncline, and south of this is found the northern limb of another anticline of slates, the southern limb not being exposed. Still farther south is the jasper of Lee and Tower Hills, which appears to form the southern and western edges of a complex syncline. All of these folds pitch toward the east.

The ore deposits are found to conform in occurrence to the laws worked out by Van Hise in reference to other districts of the Lake Superior region; that is, (1) they occur for the most part in pitching troughs with impervious basements. Usually this impervious basement is one or more of the different varieties of the eruptive rocks. (2) They are secondary concentrations produced by downward percolating waters, the silica being leached out and the iron ore deposited.

Smyth, (H. L.),[1] describes a quartzite tongue in the jasper at Republic. This tongue branches from the main mass of quartzite, and after continuing nearly parallel with it for a long distance, tapers to a point toward the north in a mass of specular jasper. The quartzite tongue includes between itself and the main quartzite a similar jasper tongue, which starts in the north from the jasper, and tapers to a point toward the south in the quartzite, the two tongues interlocking. These

[1] The Quartzite Tongue at Republic, Michigan, by H. L. Smyth. Journal of Geology, Vol. II, 1894, pp. 680–691.

unusual relations are explained as due to faulting approximately parallel to the fold which occurred during the folding of the series.

Van Hise[1] describes the rocks of the Marquette district as constituting a great synclinorium. The axial planes of the minor folds on the sides dip toward the center of the synclinorium, thus resembling the fan structure of the Alps; but there is the great difference that the major fold is a synclinorium rather than an anticlinorium. This kind of fold may be called the Marquette type.

Clements[2] describes the volcanic rocks of the Michigamme district of Michigan. The succession in the district from the base up is (1) granite and gneiss, cut by basic dikes; (2) quartzose limestone formation, with an estimated thickness of 1500 to 2000 feet; (3) a great series of volcanics, with an average thickness of about 3000 feet; (4) a set of sedimentaries consisting of quartzites, slates, and iron formation material. The volcanics include apobasalts, apo-andesites, and aporhyolites, each occurring both as lavas and as tuffs. The lavas are frequently amygdaloidial.

Smyth (H. L.),[3] compares the Lower Menominee and Lower Marquette series in Michigan. The Lower Menominee series consists in ascending order of

1. A basal quartzite, rarely conglomeratic, having a thickness of 700 to 1000 feet.
2. A crystalline limestone, averaging 700 to 1000 feet in thickness.
3. Red, black, and green slates, not known to exceed 200 or 300 feet in thickness, and containing the iron formation that gives the rich ores of Iron Mountain and Norway. Toward the north the horizon of the slates is in part occupied by later eruptives, that rapidly increase in thickness and attain a maximum of nearly 2000 feet.
4. The Michigamme Mountain jasper. The least modified phase seems to be in part at least a sediment. The most highly altered kind is like the banded, specular jasper of Republic.

[1] Character of Folds in the Marquette Iron District, by C. H. VAN HISE. Proc. Am. Assoc. for Adv. of Sci., for 42d Meeting, 1894, pp. 171. (Abstract.)

[2] The Volcanics of the Michigamme District of Michigan (preliminary), by J. MORGAN CLEMENTS. JOURNAL OF GEOLOGY, Vol. III, 1895, pp. 802–822.

[3] Relations of the Lower Menominee and Lower Marquette Series of Michigan (preliminary), by H. L. SMYTH. Am. Jour. Sci. (III), Vol. XLVII, 1894, pp. 216–223.

The Lower Marquette series in the western part of the Marquette area consists in ascending order of

1. A basal conglomerate, quartzite, quartz-schist—probably less than 100 feet.

2. An iron-bearing formation which may be divided into a lower actinolitic schist and an upper banded red jasper and specular hematite. The iron-bearing member has a maximum thickness of more than 1000 feet.

The magnetic jasper of Michigamme mountain by means of outcrops and magnetic work, has been traced within one and one-half to two miles of the iron-bearing formation of the Marquette series, and the two are regarded as equivalent. If this be true, the Lower Marquette quartzite may represent the lower quartzitic portion of the Michigamme jasper formation, in which case the whole of the Lower Marquette series would be represented by the highest member of the Lower Menominee.

The absence in the Marquette district of the equivalent of the great thickness of limestone, quartzite, and eruptives below the Michigamme jasper in the Menominee district is accounted for by supposing that the Marquette area was more elevated, and that the transgression of the ocean from the south reached the Marquette district when the lower portion of the Michigamme jasper was being deposited. If the above correlation be correct it further follows that the principal ore formation of the Menominee has no equivalent in the Marquette district.

The Mount Mesnard series of quartzite, limestone, and slates, as described by Wadsworth, in the eastern part of the Marquette area, between the Cascade range and Lake Superior, has many points of resemblance to that part of the Lower Menominee series below the Michigamme jasper. The age of the Mount Mesnard series is still in doubt, but if it should prove to underlie the Lower Marquette (Wadsworth's Republic formation), its position would probably indicate the limit of the old Marquette highland on the eastern side.

COMMENTS.

One point upon which additional evidence seems to be necessary is that the slates bearing iron ores in the Menominee district proper are really equivalent to the slates associated with eruptives farther north. If these are not equivalent, it is possible that the Michigamme

jasper and these iron-bearing slates are the equivalents of the iron-bearing formation and the quartzite below in the Marquette district. If the latter proves true the principal ore horizon of the Menominee may have an equivalent in the Marquette district.

Weidman[1] describes the igneous rocks of the Lower Narrows of the Baraboo River. These are in a belt from one-eighth to one-half mile wide, running for four miles in a direction east and west. Chemical and microscopical study shows this rock to be a quartz-keratophyre. It is shown to be a volcanic rock by its flowage structure, broken crystals, and by volcanic breccias. The rock has a schistosity parallel to the bedding of the quartzite. The quartz-keratophyre rests upon the topmost layer of quartzite, with a possible erosion interval. It has been folded with the quartzite, and like that rock rests unconformably below the undisturbed Cambrian.

Beyer[2] describes spotted slates associated with the Sioux quartzite series in the northeast corner of Minnehaha county, South Dakota. The quartzite here grades up into reddish slate, which in lithological character corresponds to the quartz-slate described by Irving and Van Hise in the Penokee series of Michigan and Wisconsin.

Bayley[3] gives fully the field occurrences, relations, and petrography of the eruptive and sedimentary rocks of Pigeon Point. The oldest rocks are interbedded Animikie slates and quartzites. Cutting the Animikie rocks is an olivine-gabbro, which occupies all the higher portions of the point. It is in all probability the lower portion of a large dike, whose upper part has been removed by denudation. Between the gabbro and the bedded rocks in many places are successively a coarse-grained red rock, a fine-grained red rock (quartz-keratophyre) and a series of contact rocks. The main masses of the keratophyre occupy a position between the Animikie sedimentaries

[1] On the Quartz Keratophyre and Associated Rocks of the North Range of the Baraboo Bluffs, by SAMUEL WEIDMAN. Bull. Univ. of Wis., Sci. Ser., Vol. I, 1895, pp. 35–56, pls. 1–3.

[2] The Spotted Slates Associated with the Sioux Quartzite. by S. W. BEYER Johns Hopkins Univ. Circulars, No. 121, 1895, p. 10.

[3] The Eruptive and Sedimentary Rocks on Pigeon Point, Minn., and their contact phenomena, by W. S. BAYLEY. Bull. 109, U. S. G. S., with maps and plates. Washington, 1893.

and the gabbro. This rock has all the characteristics of an eruptive younger than the gabbro. The coarse-grained rocks between the gabbro and the keratophyre are intermediate in character between the two, and grade into them. They are therefore regarded as a contact product formed by the intermingling of the gabbro and keratophyre magmas. The keratophyre also apparently grades into the Animikie slates and quartzites, there being three zones showing different grades of alteration of the sedimentary rocks, due to the contact with the igneous rock.

From the peculiar relations it is regarded as probable that the keratophyre is of contact origin; that is, it was produced by the fusion of the slates and quartzites of the Animikie through the action upon them of the gabbro. The magma thus formed then acted in all respects like any intrusive magma. It penetrated the surrounding rocks in the form of dikes, and solidified as a soda-granite under certain circumstances, and under others as a quartz keratophyre. Cutting all of the previously mentioned rocks are diabase dikes.

Bayley[1] gives a detailed petrographical study of the basic, massive rocks of the Lake Superior region and especially of the great gabbro of northeastern Minnesota. The normal phase of the gabbro is found to have a typical granitic structure and to differ essentially from all of the basic intrusive rocks of the Animikie series and from all other Keweenawan basic rocks, none of which have a distinctly granitic structure. Upon the border of the main mass of gabbro are peculiar rocks which are interlaminated with quartzose bands. These are shown to be but peripheral phases of the gabbro. It is concluded that further field work will probably show that the gabbro is either a batholite, well toward the base of the Keweenawan series, or that it is a eroded mass upon top of which the later Keweenawan beds have been deposited.

Elftman[2] finds that the great gabbro of northeastern Minnesota has a rude arrangement of the rock in parallel layers similar to the

[1] The Basic Massive Rocks of the Lake Superior Region, by W. S. Bayley. Journ. of Geol., Vol. I, 1893, pp. 433–456, 587–596, 688–716; Vol. II, 1894, pp. 814–825; Vol. III, 1895, pp. 1–20.

[2] Notes upon the Bedded and Banded Structures of the Gabbro and upon an Area of Troctolyte, by A. H. Elftman, 23d Ann. Rep. Geol. and Nat. Hist. Sur. of Minn. for 1894, part XII, 1895, pp. 224–230.

layers of sedimentary rocks. This structure usually dips to the south. It does not depend upon the differentiation of the mineral components of the rocks, but seemingly is due to secondary causes which acted upon the rock after it had solidified. This sheeted structure is a common phenomenon along the northern limits of the mass. The gabbro has also a banded structure due to the parallel arrangement of the mineral constituents. The bands are not regularly arranged, appearing and disappearing in a manner which shows them to be not independent of the secondary causes. This structure is present to a marked degree in the central portion of the gabbro.

Large feldspar masses occur in the gabbro in the southeastern parts of T. 61 N., Rs. 10 W. and 11 W. The mass in the latter township has a marked banding. The line of division between the feldspar masses and the normal rock is sharp in the field and in the hand specimen. Both are, however, regarded as differentiations from the same magma.

In the southern part of T. 62 N., R. 10 W., the eastern part of T. 61 N., R. 11 W., the greater part of T. 61 N., R. 10 W., and in adjacent townships is a considerable area of dark, reddish-colored olivine-gabbro or troctolyte, which has both a sheeted and banded appearance. This rock and the normal gabbro have not been seen in contact, but wherever they closely approach each other, often within a few feet, both preserve their characteristic structure, and there is no sign of the transition of the one into the other. The olivine rock appears to be above the ordinary gabbro.

Hubbard[1] gives two geological cross-sections of the Keweenawan series in the vicinity of the Calumet and Hecla and the Tamarack mines. The strata here consist of interstratified traps, amygdaloids, sandstones, and conglomerates. Deep in the series there is less amygdaloid, and it is suggested that the amygdaloids are largely pseudo-amygdaloidal, their development being dependent upon sub-surface weathering. It is found that the conglomerates approach each other in passing from the north toward the south, due to the thinning of the igneous beds. The Eastern sandstone, somewhat remote from the line of junction with the Keweenawan series, has at places a dip toward the traps as high as 10° or 12°. At Lake Linden this formation is

[1] Two New Geological Cross-sections of Keweenaw Point, by L. L. HUBBARD. Proceedings of the L. S. Mining Inst., Vol. II, 1894, pp. 79–96.

shown by boring to be at least 1500 feet thick, and to consist of red sandstone with several streaks of marl. The likeness of this sandstone to the upper Keweenawan sandstone, the faulting along or near the contact line of the two formations, and the thinning of the traps and amygdaloids in passing toward the Eastern sandstone, seem to strongly favor the theory that the two formations are of the same age.

COMMENTS.

The question of the relations of the Eastern sandstone to the Keweenawan is too difficult a one to discuss here, but it may be said that it is the reviewer's opinion that the evidence presented is far too slight for so important a conclusion. For a comprehensive discussion of the question the reader is referred to Bulletin 23 of the United States Geological Survey.

Winchell,[1] discusses the origin of the Archean greenstones. The great bulk of them are pyroclastic. They were distributed and somewhat stratified by the waters of the ocean into which the material fell. As evidence of their arrangement by water is their very general strati-form structure, which can only be explained by the action of water. This structure stands vertical or nearly so. These greenstones constitute a distinct terrane, forming the latest portion of the Keewatin, at the top of the Fundamental Complex of the Lake Superior region. Below the greenstones are found chloritic slates and schists, chloritic schists, clay-slates, graywackes, conglomerates, quartzites, novaculites, and jaspilites. The thickness of the greenstones in Minnesota exceeds that of any other Archean terrane. The Keewatin passes gradually down into crystalline mica-schists or hornblende-schists, and finally into acid gneiss.

COMMENTS.

In certain parts of the Lake Superior region the greenstones are predominantly pyroclastic, and in other parts are predominately intrusive or extrusive lavas. Not only is this so, but within the same series in the same district the basic igneous rocks in one part are mainly tuffs, and in other parts are almost wholly massive.

I would altogether dissent from the conclusion that the banding of the igneous rocks alone is evidence of their arrangement by water. In

[1] The Origin of the Archean Greenstones, by N. H. WINCHELL. 23d Ann. Rep. Geol. & Nat. Hist. Sur. of Minn., for 1894, Part II, 1895, pp. 4–35.

certain areas and series the banded pyroclastics have been largely deposited in water; in other areas and series there is no evidence whatever of such deposition.

The pyroclastics south of Lake Superior, instead of belonging to a single terrane, belong to at least three, distinct, unconformable series. From the base up these are the Archean or Fundamental Complex, the Lower Huronian, and the Upper Huronian. Furthermore, while year after year evidence has been sought upon this point, we have been wholly unable to show that any of the Archean tuffs of the south shore were deposited in water. However, the tuffs of the Lower Huronian and the Upper Huronian have been largely deposited in water, and between ordinary sedimentary rocks showing little or no tufaceous material and ordinary tuffs which give no evidence of water arrangement, there are all gradations.

Winchell[1] reviews the stratigraphy of the Lake Superior region. In reference to the Keweenawan series he reaches the following conclusions: (1) The eruptive rocks which in Michigan, Wisconsin, and Minnesota have been included in the Keweenawan, consists of two widely differing series of widely separated ages. Included in these pre-Keweenawan eruptives are the great gabbro of Minnesota and the red rocks such as those at the Palisades and at Pigeon Point. This eruptive period is called the Animikie revolution. (2) This period was followed by a long erosion interval, during which were deposited the Sioux quartzites of Dakota, the New Ulm quartzites of Minnesota, the Baraboo and Barron quartzites of Wisconsin, and the quartzites and conglomerates below the Keweenawan diabases in the Penokee district. In the New Ulm quartzites are found "taconite" jasper pebbles, and these are taken as evidence that this material was derived from the Animikie. (3) Following this conglomerate and quartzite is the Keweenawan eruptive age, which separates the Paradoxides horizon from the Dicellocephalus horizon. (4) The Olenellus horizon is separated from the Paradoxides horizon by the disturbance that closed the Animikie.

The general succession for the Lake Superior region is given as follows:

[1] Crucial Points in the Geology of the Lake Superior Region by N. H. Winchell, Am. Geol., Vol. XV, 1895, pp. 153–162, 229–234, 295–304, 356–363, and Vol. XVI, 1895, pp. 12–20, 75–86, 150–162, 269–274, 331–337.

<table>
<tr><td colspan="2">Upper Cambrian.

Olenus zone.</td><td>St. Croix.
Eastern sandstone.
Lake Superior sandstone.
Nipigon formation.
(The Dicellocephalus — "Potsdam" of New York).</td><td rowspan="2">Progressive subsidence.</td></tr>
<tr><td rowspan="3">Taconic (or Middle and Lower Cambrian).</td><td>Keweenawan. *Paradoxides zone.*</td><td>Keweenawan.
Traps and underlying Quartzite and Conglomerate.
Potsdam at Potsdam, N. Y., and eastward to the Au Sable River.</td></tr>
<tr><td colspan="3">Non-conformity.</td></tr>
<tr><td>Animikie. *Olenellus zone; Foraminifera.*</td><td colspan="2">Animikie slates.
Pewabic and Wauswaugoning quartzites.
Penokee series.
Mesabi iron range.
Misquah hills.
Gabbro and Anorthosite range.
Norian.
Upper Laurentian.
Bohemian range and South Copper range in Michigan.
Minong range, Isle Royal.</td></tr>
<tr><td colspan="4">The Great Non-Conformity.</td></tr>
<tr><td rowspan="3">Archean.</td><td rowspan="2">Ontarian.</td><td colspan="2">Keewatin.</td></tr>
<tr><td colspan="2">Coutchiching.</td></tr>
<tr><td colspan="3">Laurentian.</td></tr>
</table>

The following general conclusions are reached as to the Lake Superior region and other parts of the United States :

The rocks of the Cortland series (the clastics), of the original Taconic area, and of the upper series of the Adirondacks are of the same age, *i. e.*, Taconic or Lower Cambrian.

The basic rocks of the Norian or Upper Laurentian system of Canada are of the same age as the gabbros of the Adirondacks.

The Taconic in America embraces all the strata containing any known fossils older than those in the Dicellocephalus or Upper Cambrian. It is separated from the Archean by a profound unconformity.

The Animikie strata in Minnesota and in general the upper iron-

bearing series of the Lake Superior region are of the age of the Taconic.

The Taconic age is represented in the Lake Superior basin, as in New England and Newfoundland, by a great series of quartzites and slates, and a few limestones.

Those rocks which have been described and mapped as Keweenawan embrace three eruptive systems, separable by two erosion intervals marked by basal conglomerates and by faunal differences, viz., the eruptives of the Animikie revolution, those of the Keweenawan proper, and the eruptives of the regions of Thunder Bay and Black Bay.

It is added as a corollary to the foregoing that the ocean which covered the spot where North America was to exist was subject to forces which acted simultaneously over a very wide area, producing oceanic deposits of like nature and of like succession in widely separated regions; and, again, that some other widely operating forces caused the simultaneous elevation, depression, and finally the breaking of the earth's crust and the escape of vast quantities of basic rock at various points far distant from one another.

COMMENTS.

Professor Irving[1] was perfectly well aware that under the term Keweenawan, as used by him, there are included two great divisions of rocks. The coarse gabbros of Wisconsin and Minnesota, cut by red rocks, are so sharply separated from the remainder of the Keweenawan that he was tempted to separate the two and place the former in the Huronian. Between the two he says there is a certain sort of unconformity. His belief in the difference between the two is further emphasized by his map of northeastern Minnesota, on which the two were for the first time given separate colors. The difference, therefore, between Professor Irving[2] and Professor Winchell upon the first conclusion is mainly one of nomenclature.

The reviewer either dissents from each of the remaining conclusions of Professor Winchell, or holds that we have no definite knowledge in reference to them.

C. R. VAN HISE.

[1] The Copper-bearing Rocks of Lake Superior, by R. D. IRVING, Mon. V. U. S. G. S., pp. 144–145, 155–156. 1883.

[2] Classification of Early Cambrian and pre-Cambrian Formations, by R. D. IRVING. 7th Ann. Rep., U. S. G. S., Pl. XLI. 1885–6.

ABSTRACTS.

The Relation between Ice-Lobes South from the Wisconsin Driftless Area. By FRANK LEVERETT, Denmark, Iowa.

Instead of a coalescence of ice-lobes from the east and west sides of the driftless area in the drift-covered district to the south there was an invasion and withdrawal of one lobe (the western) before the other reached its culmination. The eastern lobe encroached upon territory previously glaciated by the western, depositing a distinct sheet of drift and forming at its western limits a well-defined morainic ridge. There appears to have been a period of considerable length between the withdrawal of the western lobe and the culmination of the eastern.

Subsequently, however, there was a readvance of the lobe on the west into northeastern Iowa, and this readvance appears to have been contemporaneous with the nearly complete occupancy of northwestern Illinois by the eastern ice-lobe. It seems not improbable that the ice-lobes were then, for a brief period, coalesced for a short distance about the south border of the driftless area. Evidence of complete coalescence, however, is not decisive so far as yet discovered.

These developments serve to throw light upon the cause for the scarcity of lacustrine deposits in the driftless area. They show that there was at most but a brief period in which the southward drainage of the driftless area was completely obstructed by the ice-sheet.

The Production of Coal in 1894. By EDWARD W. PARKER. *Extract from the 16th Annual Report of the U. S. Geological Survey, Part IV., Mineral Resources of the United States.*

This report, consisting of 224 pages, constitutes the first chapter of Part IV. of the 16th annual report of the Director, the well-known volume of "Mineral Resources" having, by a recent act of Congress, been made a part of the Directors' report. This chapter, with four others, has been published and given to the public in advance of the complete volume. As indicated by the title, the chapter is principally a statistical compilation, giving in great detail the record of coal production

in 1894, with a résumé of the industry in previous years. The tables show the production by fields, such as the Appalachian, the Central, the Western, etc.; by states and by counties in the states. They also show the value of the output, and the number of men employed, and the amount of time taken to win it. The result of the prolonged strike in the bituminous regions is shown in a reduced production in 1894 as compared with 1893 of more than eleven and a half million tons. The loss in labor to the miners and other employés who were thrown out of employment by the strike is shown to have been the equivalent of 5,167,357 men for one day, or of 17,224 men for one year of 300 working days.

The effects of the business depression and general low value for commodities is illustrated in the coal mining industry by a decrease in the value of the product in 1894 of over $22,000,000, more than ten per cent. less than that of 1893, while the amount of the product was only 6 per cent. less than the preceding year.

An interesting feature of Mr. Parker's report is a series of contributions from secretaries of boards of trade, etc., in the larger cities, which furnishes useful information regarding the coal trade of those cities, and the effects of the strike and other influences upon the movement of coal from the producing to the consuming centers.

Merocrinus Salopiæ, n. sp., and another Crinoid, from the Middle Ordovician of West Shropshire. By F. A. Bather. *Geol. Mag., n. s.,* Vol. III, pp. 71–75, February 1896.

Merocrinus is a genus of dicyclic inadunate crinoids, hitherto recorded only from the Utica shale of Ohio (Ulrich) and the Trenton limestone of New York (Walcott). The discovery of a species in the Middleton group, Meadow Town series of Mincop in Shropshire, England, is therefore of interest to American geologists. It is thus diagnosed: "Radials and Basals, as high as wide. Arms slender, bifurcating at intervals of eight or more ossicles. Brachials wider, or with a slight cornice at their distal margin." The other crinoid described and figured presents peculiar features, especially in the arms, but is too imperfect to be referred to any known genus.

U. S. Geologic Atlas. Folio 10, Harper's Ferry, Virginia; Maryland; West Virginia, 1894.

This folio consists of four pages of descriptive text, signed by

Arthur Keith, geologist; one page of columnar section, a topographic map (scale 1:125000), a sheet showing the areal geology of the district; another showing the economic geology, and a third exhibiting structure sections.

The folio describes that portion of the Appalachian province which is situated between parallels 39° and 39° 30′ and meridians 77° 30, and 78°. The tract contains about 950 square miles, and falls within Washington and Frederick counties, Maryland; Loudoun and Fauquier counties, Virginia; and Jefferson county, West Virginia.

The folio begins with a general description of the province, which shows the relation of the Harper's Ferry tract to the whole. The local features of the drainage by the Potomac and Shenandoah Rivers and their tributaries (Goose, Antietam, and Catoctin Creeks) are treated. The various forms of the surface are pointed out, such as Shenandoah Valley, Blue Ridge, and Catoctin Mountain, and their relations to the underlying rocks are made clear.

Under the heading Stratigraphy the geologic history of the Appalachian province is presented in outline, and the local rock groups are fully described in regard to composition, thickness, location, varieties, and mode of deposition.

The formations range in age from Algonkian to Cretaceous, the greater portion being Algonkian, Cambrian and Silurian. The Silurian rocks appear in Shenandoah Valley, the Cambrian in Catoctin Mountain and Blue Ridge, the Algonkian between these ridges, and the Juratrias east of Catoctin. The Algonkian rocks are chiefly granite and epidotic schist; the Cambrian rocks, sandstones and shales, passing up into limestones; the Silurian rocks, limestones and shales; and the Juratrias rocks, red sandstone and shale and limestone conglomerate. The details of the strata are shown in the columnar section. The manner in which each kind of rock decays is discussed, and how the residual soils and forms of surface depend on the nature of the underlying rock.

In the discussion of Structure, after a general statement of the broader structural features of the province, three methods are shown in which the rocks have been deformed. Of these the extreme Appalachian folding is the chief; next is that developed in the Juratrias rocks; and least in importance are the broad vertical uplifts. Three degrees of extreme deformation appear in the Palæozoic rocks — folding, faulting, and metamorphism — each being best developed in a certain kind

of strata. Between Blue Ridge and Catoctin Mountain the Algonkian or oldest rocks appear on a great anticlinal uplift, with Cambrian rocks on either side. Faults appear chiefly on the west side of this uplift, and metamorphism increases toward its side. In Shenandoah Valley the rocks are folded to an extreme degree, and the strata are frequently horizontal or overturned. The Juratrias rocks always dip toward the west, and are probably repeated by faults different in nature from the Appalachian faults. In the sheet of sections the details of the folds and faults appear.

Economic products of this region comprise copper and iron ore; ornamental stones, such as marble, limestone conglomerate, and amygdaloid; building stones, such as sandstone, limestone, and slate; and other materials like lime, cement, brick-clay, and road materials. The localities of each of these materials are noted and quarries located on the economic sheet, and the character and availability of the deposits are discussed.

Geologic Atlas of the United States. Folio 2, Ringgold, Georgia, Tennessee, 1894.

This folio consists of three pages of text, signed by C. Willard Hayes, geologist; a topographic sheet (scale 1:125,000), a sheet of areal geology, one of economic geology, one of structure sections, and one giving columnar sections.

Geography.—The district of country covered by this folio lies mainly in Georgia, a narrow strip about a mile in width along its northern border extending into Tennessee. It embraces portions of Dade, Catoosa, Walker, Whitfield, Chattooga, Floyd, and Gordon counties in Georgia, and of Madison, Hamilton, and James counties in Tennessee. The region forms a part of the great Appalachian Valley. Its surface is marked by three distinct types of topography viz.: plateaus, formed by hard rocks whose beds are nearly horizontal; sharp ridges, formed by hard rocks whose beds are steeply inclined; and level or undulating valleys, formed on soft or easily eroded rocks. The plateaus are confined to the western third of the district, and include portions of Lookout and Sand mountains. Their surface is generally level or rolling, with a slight inclination from the edges toward the center, giving the plateaus the form of a shallow trough. They are bounded by steep escarpments rising from 1000 to 1200 feet above the surrounding valleys. The sharp ridges are confined to

the eastern third of the district, while a broad undulating valley occupies its central portion. The latter is drained in part northward by tributaries of the Tennessee and in part southward by streams flowing directly to the Gulf. The divide separating the two drainage systems is broad and low, and there is evidence that the Tennessee River formerly flowed southward across the divide.

Geology—The rocks appearing at the surface within the Ringgold district are entirely of sedimentary origin, and include representatives of all the Palæozoic groups. The oldest rocks exposed are shales, sandstones, and thin-bedded limestones of Lower and Middle Cambrian age. These are called the Apison shale, Rome sandstone, and Conasauga shale. Above these formations is a great thickness of siliceous magnesium limestone, the Knox dolomite, the lower portion probably being Cambrian and the upper portion Silurian. The remaining Silurian formations are the Chickamauga limestone and the Rockwood sandstone. The Devonian is either wholly wanting or is represented by a single thin bed of carbonaceous shale, not over 35 feet in thickness. Above the Chattanooga black shale are the Fort Payne chert, Floyd shale, and Bangor limestone forming the Lower Carboniferous, and the Lookout and Walden sandstones forming the Coal Measures. Most of the formations thicken eastward, and at the same time the proportion of calcareous matter decreases, showing that the land from which the materials composing the rocks were derived lay to the east.

The region has been subjected to compression in a northwest-southeast direction, and the originally horizontal strata would have been thrown into a series of long, narrow folds whose axes extend at right angles to the direction of the compression, or northeast and southwest, The effects of compression were greatest in the eastern portion of the district, where the strata are now all steeply inclined and the basal beds form sharp ridges, while in the western portion considerable areas of strata remain nearly horizontal and form plateaus. Where the folding was greatest there was also much fracturing of the rocks, and the strata on the eastern side of a fracture are in many places thrust upward and across the broken edges of the corresponding strata on the west. Most of the ridges in the district have thrust faults of this character along their eastern basis.

Mineral Resources.—These consist of coal, iron ore, mineral paint, manganese ore, limestone, building stone, and brick and tile clay. The productive coal-bearing formations, the Lookout and Walden

sandstones, occupy the upper portions of Pigeon, Lookout and Sand mountains, having an area in this district of 116 square miles. The Lookout generally contains one, and in some places two or three, workable coal seams, but they are variable in position, extent, and thickness. The Walden sandstone forms a considerable area on Lookout Mountain, and contains at least one valuable seam of coal, which is extensively worked at the Durham mines. Two varieties of iron ore are found in workable quantities. The first is the red fossil or "Clinton" ore, which occurs as a regularly stratified bed in the Rockwood formation, and is worked at various places along the base of Lookout Mountain. The second variety is limonite, which occurs as a pocket deposit at the base of several of the ridges along the eastern border of the district. Associated with the latter, particularly along the faults, are deposits of manganese, generally as nodules scattered through the surface soil.

Geologic Atlas of the United States. Folio 4, Kingston, Tennessee, 1894.

This folio consists of three and one-half pages of text, signed by C. Willard Hayes, geologist; a topographic sheet (scale 1 : 125,000), a sheet of areal geology, one of economic geology, one of structure sections, and one giving columnar sections.

Geography.—The map is bounded by the parallels 35° 30′ and 36°, and the meridians 84° 30′ and 85°. The district represented lines wholly within the state of Tennessee, and includes portions of Cumberland, Morgan, Roane, Rhea, Loudon, Meigs, and McMinn counties. Its area is approximately 1000 square miles, and it forms a part of the Appalachian province, being about equally divided between the valley and plateau divisions of the province. The northwestern half of the district is a portion of the Cumberland Plateau. The surface of this half, except in the Crab Orchard Mountains, is comparatively level and has an altitude of between 1800 and 1900 feet. Its streams flow in shallow channels until near the edge of the plateau, when they plunge into rocky gorges which form deep notches in the escarpment. The Crab Orchard Mountains are formed by the uneroded portions of an anticline, the hard bed rising in the form of a low arch. Toward the southwest the hard beds were lifted higher, and have been removed, exposing the easily erodible limestone beneath, and in this the Sequatchie Valley has been excavated. The southeastern half of the district

lies within the great Appalachian Valley, here occupied by the Tennessee River, which flows at an altitude of about 700 feet, and above which rounded hills and ridge rise from 300 to 500 feet higher. The valley ridges have a uniform northeast-southwest trend, parallel with the Cumberland escarpment, their location depending on outcrop of narrow belts of hard rocks.

Geology.—West of the Cumberland escarpment the geologic structure is very simple. The strata remain nearly horizontal, as they were originally deposited, except in the Crab Orchard Mountains, where they bend upward, forming a low arch. East of the escarpment the strata have suffered intense compression, which has forced them into a great number of narrow folds whose axes extend northeast and southwest. The strata dip more steeply on one side of the arch than on the other; and as a further effect of compression, the beds on the steeper (generally the northwestern) side have been fractured and the rocks on one side thrust upward across the broken edges of those on the other. In this manner the folds first formed have in most cases been obliterated, and there remain narrow strips of strata separated by faults, and all dipping to the southeast.

The rocks appearing at the surface are entirely sedimentary—limestones, shales, sandstones, and conglomerates—and include representatives of all the Palæozoic groups. The Cambrian formations consist of the Apison shale, Rome sandstone, and Conasauga shale, a series which is calcareous at top and bottom and siliceous in the middle. The Conasauga passes upward through blue shaly limestone into the Knox dolomite, a formation about 4000 feet in thickness, composed of siliceous or cherty magnesian limestone. Probably the lower portion is of Cambrian age, while the upper is undoubtedly Silurian. Above the dolomite is the Chickamauga limestone, whose upper portion toward the eastern side of the district changes from blue flaggy limestone to calcareous shale, and is called the Athens shale. The next formation is the Rockwood, which also changes toward the east from calcareous shale to hard, brown sandstone. These changes in the character of the rocks indicate that, while they were forming, the land from which their materials were derived lay to the southeast. The Devonian is represented in this region by a single stratum of carbonaceous shale, the Chattanooga black shale, which rests, probably with a slight unconformity, on the Rockwood. Above the Chattanooga are the Fort Payne chert and Bangor limestone of the lower

Carboniferous, and the Lookout and Walden sandstones of the Coal Measures.

Mineral resources.—These consist of coal, iron ore, limestone, building stone, and clay. The coal-bearing formations, the Walden and Lookout, form the surface of the greater part of the district northwest of the Cumberland escarpment, making a probably productive area of 370 square miles. The Lookout always contains one and sometimes as many as four beds, all of which are locally though not generally workable. The upper bed, immediately below the conglomerate, is the most constant. The greater part of the workable coal is contained in the Walden, the lower bed probably corresponding to the Sewanee seam farther west. This occurs in a belt six or eight miles in width along the eastern edge of the plateau. The only iron ore sufficiently abundant to be commercially important is the red fossil ore, which occurs as a regularly stratified bed in the Rockwood formation. The numerous folds east of the escarpment bring the Rockwood to the surface in long, narrow bands, along which the ore has been worked at many points. It varies in thickness from three to seven feet, and although at some places it passes into a sandy shale, it is generally a high grade ore.

Geologic Atlas of the United States. Folio 6, Chattanooga, Tennessee, 1894.

This folio consists of three pages of text, signed by C. Willard Hayes, geologist; a topographical sheet (scale 1 : 125,000), a sheet of areal geology, one of economic geology, one of structure sections, and one giving columnar sections.

Geography.—The map is bounded by the parallels 35° and 35° 30′ and the meridians 85° and 85° 30′. The district is wholly within the State of Tennessee, embracing portions of Bledsoe, Rhea, Sequatchie, Marion, Hamilton, and James counties. It lies partly in the great Appalachian Valley and partly in the plateau division of the Appalachian province. Its surface is marked by two distinct types of topography, the plateau and the valley. The former prevails in the western half of the district, which is occupied by portions of the Cumberland Plateau and Walden Ridge, the two plateaus being separated by Sequatchie Valley. The Cumberland Plateau has an altitude of about 2100 feet, with a level or rolling surface. Walden Ridge has an altitude of 2200 feet along its western edge, and slopes gradually eastward down to 1700 feet. Both plateaus are bounded by abrupt escarpments

from 900 to 1400 feet in height, the upper portions being generally formed by a series of cliffs. The two plateaus are separated by Sequatchie Valley, which is about four miles in width. Its western side, the escarpment of Cumberland Plateau, is notched by numerous deep, rocky gorges, cut backward into the plateau by streams flowing from its surface; while the eastern side, the Walden escarpment, forms an unbroken wall. The eastern half of the district is occupied by the Tennessee Valley, the river itself having an altitude of between 600 and 700 feet, while rounded hills and irregular ridges rise several hundred feet higher. Leaving the broad valley, which continues southward into Alabama, the Tennessee River turns abruptly westward at Chattanooga and enters a narrow gorge through Walden Ridge. This part of its channel is very young in comparison with the valley toward the north, and there is evidence that the river has occupied its present course but a short time, having formerly flowed southward directly to the gulf.

Geology.—The rocks appearing at the surface within the limits of the map are entrely of sedimentary origin, and include representatives of all the Palæozoic groups. The Cambrian formations include the Apison shale, Rome sandstone, and Conasauga shale, a series which is calcareous at top and bottom and siliceous in the middle. The Conasauga passes upward through the blue limestone into the Knox dolomite—a great thickness of siliceous magnesium limestone, the lower portion of which is probably Cambrian. Above the dolomite are Chicamauga limestone and Rockwood shale, the latter becoming brown sandstone in White Ash Mountain. The whole of the deposition which took place in this region during the Devonian is apparently represented by a stratum of shale from ten to twenty-five feet in thickness—the Chattanooga black shale, which probably rests unconformably upon the Rockwood. Above the Chattanooga are the Fort Payne chert and Bangor limestone, forming the lower Carboniferous, and the Lookout and Walden sandstones, forming the Coal Measures. Nearly all the formations exhibit an increase in thickness and in proportion of sand and mud toward the east, showing that the land from which their materials were derived lay to the east and southeast.

The geologic structure is simple in the region occupied by the plateaus, and complicated in the valleys. In the Cumberland Plateau the strata are almost perfectly horizontal, while in Walden Ridge they have a slight dip from the edges toward the center. Sequatchie Valley

is located upon the westernmost of the sharp anticlines which characterize the central division of the Appalachian province. In the eastern part of the district the strata have suffered compression, which has forced the originally horizontal strata into a series of long, narrow folds whose axes extend in a northeast-southwest direction. In addition to the folding, and as a further effect of the compression which produced it, the strata have been fractured along many lines parallel with the folds, and the rocks upon one side — generally the eastern — have been thrust upward and across the broken edges of those on the other side. A fault of this character passes along the western side of the Sequatchie Valley, and several formations which would normally occur there are entirely concealed.

Mineral resources.—These consist of coal, iron ore, limestone, building stone, and brick and tile clay. The productive coal-bearing formations, the Lookout and Walden sandstones, occupy the surface of the plateaus. They have an area within the district of about 400 square miles, and contain from one to three beds of workable coal. The beds in the Lookout are generally variable in position, extent, and thickness; those in the Walden are constant over large areas, and are worked on a considerable scale at various points along the eastern side of Walden Ridge. About 200 square miles of area of these upper coals occur within the district, on the Cumberland Plateau and in the eastern half of Walden Ridge. The most important iron ore in the district is the red fossil or Clinton ore, which occurs as a regularly stratified bed in the Rockwood shale. The bed is from three to five feet thick in Sequatchie Valley, but considerably thinner in the vicinity of Chattanooga and eastward.

Geologic Atlas of the United States, Folio 8, Sewanee, Tennessee, 1894.

This folio consists of nearly four pages of text, signed by Charles Willard Hayes, geologist; a topographic sheet (scale 1:125,000), a sheet of areal geology, one of economic geology, one of structure sections, and one giving columnar sections.

Geography.—The map is bounded by the parallels 35° and 35° 30′ and the meridians 85° 30′ and 86°, and the territory it represents is wholly within Tennessee, embracing portions of Grundy, Sequatchie, Marion, Franklin, and Coffee counties. The district lies almost wholly within the western or plateau division of the Appalachian province. Crossing its southeastern corner is the Sequatchie Valley, located upon

the westernmost of the sharp folds which characterize the central or valley division of the province. The larger part of the district is occupied by the Cumberland Plateau, which has a gradual ascent toward the north, rising from an altitude of between 1700 and 1800 feet on the south to 1900 or 2000 feet on the north. The plateau is limited by a steep escarpment from 1100 to 1500 in height on the east and about 1000 feet in height on the west. Many streams have cut their channels backward into the plateau, forming deep, narrow caves, so that the escarpment forms an extremely irregular line. Small portions of Walden Ridge and Sand Mountain appear in the extreme southeastern corner of the district, these being plateaus similar to the Cumberland Plateau farther west. A small portion of the Sequatchie Valley occupies the southeastern part of the district, with an altitude of about 600 or 700 feet, while its northwestern portion is within the "highland rim" a broad terrace surrounding the lowlands of middle Tennessee and separating on the east from the Cumberland Plateau.

Geology.—The rocks appearing at the surface are of sedimentary origin, and include representatives of all the geologic periods from silurian to carboniferous. The Silurian formations, consisting of the Knox dolomite, Chickamauga limestone, and Rockwood shale, occur only, as narrow belts in the Sequatchie Valley. The same is true of the Devonian, which is represented by a single thin formation, the Chattanooga black shale. The Carboniferous formations occupy by far the larger part of the district, the Fort Payne chert and Bangor limestone forming the lower portions of the plateau escarpments and the highland rim, while the Lookout and Walden sandstones, belonging to the Coal Measures, form the summits of the plateaus.

The geologic structure of the region is in general extremely simple. The plateaus and the highland rim to the westward are underlain by nearly horizontal strata, while the Sequatchie Valley is upon a sharp, narrow fold, the beds dipping downward on either side beneath the adjoining plateaus. If the rocks which have been eroded from the top of this arch were restored, there would be a ridge several thousand feet in height in place of the present valley. In addition to the folding which the strata have suffered along this line, they have also been fractured, and the beds on the east have been thrust upward and across the edges of corresponding beds on the west of the fracture, so that along the western side of the valley the formations do not appear at the surface in their normal sequence.

Mineral resources.—These consist of coal, iron ore, limestone, building and road stone, and clays. The Coal Measures occupy an area within the district of about 500 square miles. Not all of this area, however, contains coal beds of workable thickness, while some portions contain two or three workable beds. The lower beds occurring in the Lookout sandstone, are variable in horizontal position, thickness, and extent, so that they cannot profitably be worked on a large scale; but they have been opened at many points, and supply an excellent fuel for local use. The Sewanee seam, which is found in the Walden sandstone, from 50 to 70 feet above its base, is the most important seam in the district. It has an average thickness of four to five feet over at least 80 square miles in the higher portions of the plateau, and is extensively mined for coking at Tracy and Whitwell. The iron ore of chief importance is the red fossil or "Clinton" ore, which occurs as a regularly stratified bed in the Rockwood shale. At Inman, in the Sequatchie Valley, it attains a thickness of 5.5 feet and is extensively mined.

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SALIENT POINTS CONCERNING THE GLACIAL GEOLOGY OF NORTH GREENLAND.

CONTENTS.

Possibility of continuous glaciation between Greenland and adjacent lands.—The study of the west coast of Greenland raised, but did not settle, the question of the possibility of continuous glaciation from a land mass, such as Greenland, over an intervening body of water, such as Baffin Bay and Davis Strait, to another land mass, such as the continent of North America. While the idea that the North American ice of the glacial epoch had its center in Greenland is no longer tenable, it does not appear that the possibility of such a thing has been doubted.

Even a cursory inspection of the west coast of Greenland seemed to show clearly that ice has not overridden the entire

coastal region of the island in recent times, and perhaps never. So far as could be judged from topography in passing, it did not even seem probable that ice from the main island ever crossed the narrow Waigat so as to become continuous with that on the island of Disco, although both the coast of the mainland in this latitude and the main portion of the Disco coast appear to have been glaciated. The topography of the coast bordering the Waigat is such as to suggest that the east coast of Disco has been glaciated by ice moving to the eastward from the interior of the island, while the opposite coast of Greenland appears to have been affected by ice moving toward the westward.

The plateau of Greenland often terminates abruptly near the coast, with a precipitous face 1500 to 3000 feet in height. Between this abrupt bluff and the water, there is usually no more than a narrow strip of low land, and often none. Along those parts of the coast where the ice-cap comes out to the edge of the plateau, it fails to reach the water for any considerable stretch. It is true that the ice, where it now reaches the edge of the abruptly terminated plateau, generally reaches it with a slight thickness only; but thick or thin, its edge breaks off and falls to the bottom of the cliff. Where the amount of ice breaking off and falling to the base of a cliff is great, it sometimes becomes re-united, and develops a small glacier. Such glaciers were seen both along the east side of Disco, and at various points on the coast of Greenland.

If the ice-cap on the upland were to advance more rapidly, or in greater mass, the amount of ice falling over the cliffs would be greater, and the glaciers formed at their bases would be correspondingly larger. It is conceivable that they might develop on such a scale as ultimately to become continuous with one another laterally. At the same time, by growth at their upper ends, they might become continuous with the ice-cap above. In this case the ice might move out from the interior over the coastal cliff without inflicting sufficient wear on the cliff face to greatly reduce its asperities, for the rough face would be to leeward. But it would not appear that such an ice-cap

on a plateau like that opposite the island of Disco could push out across a body of water like the Waigat, and overspread the island, without inflicting pronounced wear on the east bluff-face (stoss side) of that island. The freedom of the steep east side of Disco from such marks as the moving ice should have left, indicate that Greenland ice never surmounted it.

Further north in Whale Sound stands Herbert Island, distant but a few miles from the coast of Greenland to the south. For a considerable distance, the opposite coast of Greenland appears to have been glaciated, at some relatively recent time, by ice moving toward the coast; but the topography of the south face of Herbert Island gives no suggestion that the ice from the mainland ever reached it. The north face of Herbert Island likewise fronts a coast which may have been continuously glaciated, but there is nothing in the topography of the north face of the island, or so far as known in its drift, to indicate that ice from the north ever bridged the water which separates it from the land to the north. Other islands in similar relations might be mentioned, showing similar phenomena. Professor Chamberlin has called attention to the phenomena of Dalrymple Island,[1] and Cone Island (Fig. 1) near the entrance of Jones Sound is equally striking.

There are then in the northern waters small islands, and their number is considerable, lying near much larger bodies of land, which appear not to have been glaciated except by ice originating on themselves.

Along those parts of Greenland where the coast is less high and rugged, and where the main ice-cap reaches the edge of the upland, it does not push out to sea as a continuous sheet, but as a series of glaciers, separated from one another by high hills of the nunatak type, though not completely surrounded by ice. These ice-free mountains stand up several hundred, and in some cases one or two thousand, feet above the ice on either side. This shows that the valleys are sufficient avenues of discharge for the ice-sheet, as now developed. The amount of snow fall and ice

[1] JOUR. OF GEOL., Vol. II, p. 661.

FIG. 1. Cone Island, Jones Sound, latitude 76° 20′, near Smith Island.

FIG. 2. A nunatak on the north side of Northumberland Island.

accumulation over the interior would need to be enormously increased before these elevations would be overridden by the ice moving out from the interior. The phenomena were such as to raise the question whether snow fall and ice accumulation could ever be so increased that the ice, moving from the interior to the coast, would override these border elevations so long as present topographic relations hold. Elevations 1000 feet high in the situations referred to would not be smothered by ice if the ice-sheet were thickened 1000 feet, since in that event the ice-drainage through the valleys would be greatly augmented, and would draw down the level of the ice immediately adjacent. It is believed that the ice-cap would need to be thickened several thousand feet before the coastal regions of the island would be completely covered.

The coast of Melville Bay is now suffering more nearly uninterrupted glaciation than any other portion of the coast seen. For a considerable distance east of Cape York it is true that three-fourths, possibly four-fifths, of the coast line is of land-ice at the present time. Yet the ice-cap lying back of Melville Bay would need to be enormously thickened in order to cover the fourth or fifth of land which is now bare.

The phenomenon of floating glacier ends, seen at several points, and heretofore referred to,[1] perhaps affords a clue to the way in which water intervals between land masses might be bridged by glacier ice, so far as they can be bridged at all. If the ice of the sea, formed by the freezing of the sea water, be not disrupted for long periods of time, the ends of glaciers crowding out into it, not being able to break off and float away as bergs, might at first float. As they advanced they might thicken, and if the water be sufficiently shallow they might ultimately rest on the bottom. With the ice of the surrounding seas still remaining unbroken, the forward movement of the ice from the land might urge the glacier ice in the water basin across the bottom of the same, and up on the opposing land. But it would seem well-nigh certain that, under the extreme conditions

[1] Jour. of Geol., Vol. III, p. 875.

of climate necessary for this sequence of events, any land which the ice might invade after crossing a water interval would have an ice-cap of its own, and such an ice-cap, descending to its coasts, would come out to meet any ice-cap which might be approaching from other lands. It is conceivable that the ice-caps of adjacent lands might meet each other in the water interval now separating those lands. The line of meeting might not be midway between the two coasts, and one body of ice might have great advantage over the other. The ice of the one land mass might thus become continuous, in some sense, with the ice of another. But under these conditions all coasts would be to leeward of the ice passing over them, and the topography of leeward coasts should be recognizably different from that of stoss coasts.

The shallower the water between land masses, the easier would it be for ice from one land to bridge it and invade the other. Elevation of a region to the extent of the depth of the water intervening between two land masses, or even a little less, would obviate the difficulties in the way of continuous glaciation from the one to the other.

The phenomena of the islands of the coast of Greenland indicate that ice from the latter has not recently, if ever, overridden them. The phenomena of the Greenland coast indicate that thickening of the ice adequate even for the complete overriding of the coast has not taken place in recent times, if ever; and the phenomena, in the aggregate, raise a question as to the possibility of such overriding.

Glaciation across other bodies of water.—The same question was raised in Newfoundland. It has generally been assumed that the ice-cap from the mainland bridged the interval between Labrador and Newfoundland; but more recent studies of the glacial phenomena of the island suggest that its glaciation may have been entirely indigenous. This is the conclusion of Mr. James Howley, the geologist of the island, in spite of the fact that pieces both of labradorite and metallic copper have been found in the drift. The interior of the island is too imper-

fectly known to make it certain that both these materials may not be indigenous. It, of course, remains that the glaciation of Newfoundland may be local, without denying the possibility of the extension of ice from the mainland across even so narrow, though moderately deep, body of water as separates the island from the mainland.

Although affording no specific warrant for speculation concerning phenomena on the other side of the Atlantic, the phenomena about Greenland raise the inquiry whether continuity of glaciation from Scandinavia to the British Isles was really a fact. I am not familiar with the details of the evidence on which the current belief rests, but it seems to me difficult to believe that snow and ice could accumulate on so narrow a strip of land as Scandinavia in sufficient quantity to allow it to cross the North Sea to the British Isles, if relative elevations remained as they now are. If the water separation was much narrower and shallower than now (a result which an elevation of a few hundred feet would bring about) some of the difficulties would be obviated; but Geikie[1] finds reason for believing that the British Isles were, in general, lower than now during epochs of glaciation. Existing evidence on this point would be likely to pertain to the closing, rather than to the opening stages of an ice epoch. If the North Sea basin were overspread by a thick sheet of ice, the covering being accomplished when the land and the sea bottom were higher, a submergence considerably below the present level might be necessary to sever the continental from the island part of the ice-sheet.

Is it not true that something more than the presence of Scandinavian bowlders in Great Britain is necessary to prove continuous glaciation between these two lands? Submergence, with floating ice, might land such bowlders in Great Britain and Ireland, and they might subsequently be incorporated into till by indigenous glaciation. If there be shells in the till of Scotland which came from the bottom of the North Sea, they would seem to be good evidence of continuous glaciation across this sea

[1] Great Ice Age, 3d edition.

from the north. But may not the shells which are found be accounted for in some other way? The real question is, not how the shells in the till might have reached their present position, but how they did reach it. If Great Britain was glaciated

FIG. 3.—Profile of end of a glacier, near the head of McCormick Bay.

by ice from the northeast, its eastern and northern coasts should show the topographic features which characterize the stoss side of a land mass. The application of this criterion might be difficult, since the supposed continuity of glaciation is referred to the earlier ice epochs, the work of which has been obscured or obliterated by later glaciations, as well as by other processes. It is meant here simply to raise the question whether the evidence for continuous glaciation from Scandinavia to Great Britain does not need re-examination. Are the phenomena such as to preclude other explanations?

FIG. 4.—Side of Gable glacier near its end. East side of Bowdoin Bay.

Steep faces of glaciers.—Professor Chamberlin has repeatedly called attention to the remarkably steep faces of the average glacier in the high latitudes of the west coast of Greenland[1] (see Figs. 3, 4, 5, 6, 7, 10, and 11). I was fortunate enough to see many glaciers which Professor Chamberlin did not, and his generalization was confirmed by the facts gathered from other sources. Steep, and even vertical, faces frequently affect both the ends and the sides of the glaciers. It is not true, however, that the sides and ends of all glaciers in the high latitudes of Greenland are vertical or approximately so, though this is the general rule north of Cape York. In many cases, instead of having vertical faces, the ends and sides of glaciers slope down to the bed of the ice by steep convex curves (Figs. 6 and 7). These slopes are usually so steep as to make ascent or descent difficult, and often impossible. In a few cases only, so few as to make them conspicuous, the slopes both of ends and sides are so gentle as to allow ready ascent. In some of these cases, if not in all, the low angle was due to the exceptional accumulation of drifted snow (Fig. 8) about the borders of the glacier proper. This drifted snow had become consolidated into granular ice, so that the glacier proper had really received an addition all around its margin, giving it gentle slopes.

The phenomena of the edges and ends of the glaciers are in keeping with the phenomena of the edge of the ice-cap itself. Where the latter lies on a plain surface, its edge is not usually vertical, but its slope is so steep that ascent is difficult (Figs. 6, 8, 9). It will be seen from the figures that the angle of slope near the edge is high, but becomes rapidly less with increasing distance from the margin. Only where snow has drifted against the edge of the ice-cap, as it has done in many places, forming an extensive foot, (Fig. 8) is the slope of its edge gentle enough to make ascent comfortable at any point where it was seen.

Overhanging layers of ice.—Not only are the edges and ends

[1] Glacial Studies in Greenland, Vols. II, III, and IV, of this Journal.

FIG. 5.—Profile of a portion of the side of a glacier on the north side of Herbert Island.

of the glaciers in many cases approximately vertical, but the higher parts often overhang the lower (Figs. 3, 4, and 5). The overhang is of different types. In general it seems to be true that the overhang is dependent upon something in the structure or constitution of the ice. (1) Where the ice is made up of layers of unequal firmness, the more compact layers are likely to project out over the more granular layers beneath (Fig. 3). (2) Where there are layers of débris in the ice, the ice immediately above is likely to overhang the débris-bearing layer (Figs. 4 and 5). The overhang is usually the more pronounced the larger the amount of débris. Since the lower fourth, third, or half of the ends and edges of glaciers, as seen in section, is often full of débris, the upper half, two-thirds, or three-fourths, often overhangs the lower portion, as shown in Fig. 10.

Where the débris is in very thin zones between thin layers of ice, the overhang sometimes takes on a different phase. Here the appearance is such as to suggest that a given layer of ice has been shoved out a little over the next underlying (Fig. 11). On close examination of the ice where the photograph reproduced in Fig. 11 was taken, it was found in every case where one layer appeared to have shoved out over its subjacent neighbor, that the junction between the two was marked by a thin zone (or film) of débris. In some cases the overhang, after persisting laterally for some feet, ceased for the space of a foot or two or more (see Fig. 12), to be continued again beyond. This was sometimes repeated frequently along the contact of the layers. If the phenomenon in question were really the result of the shoving of an upper layer of ice over the one beneath, it would hardly be true that the movement would fail for a few inches (as at *bc*, *de*, *fg*, etc., Fig. 12) at frequent intervals. On cutting back into the face of the ice where this phenomenon of interrupted overhang was seen, it was found, in every case where the point was tested, that where the overhang failed, the débris between the layers also failed, and that the amount of overhang all along was in a general way proportional to the amount of débris.

FIG. 6.—A broad but very short glacial lobe from a local ice-cap near "Meteor" Bay, east of Cape York.

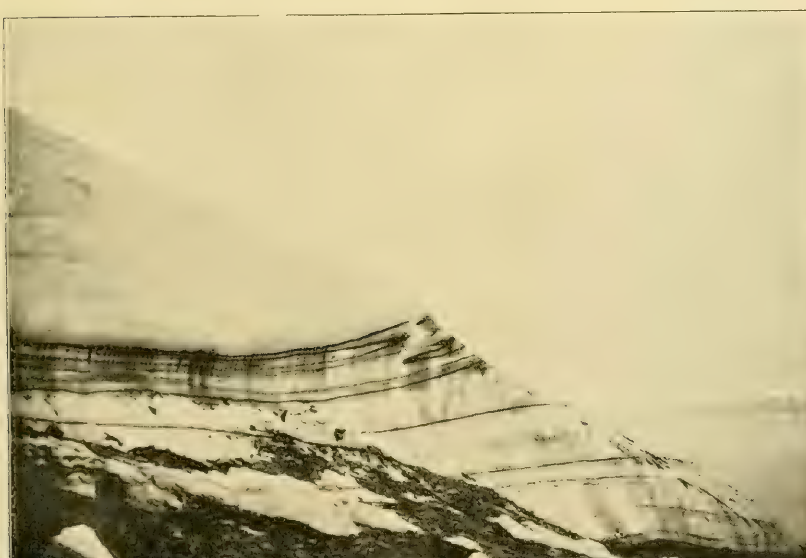

FIG. 7.—Profile of end of a glacier on north side of Herbert Island.

These relations led to the conclusion that the overhang in this, as in other cases, was the result of unequal melting, due to the unequal distribution of débris. The débris, being dark colored, absorbs the heat to a greater extent than the clean ice, and the ice behind the débris is therefore melted back more rapidly. As the thin zone which carries the débris is melted back, the water trickling down the face of the ice below carries the earthy matter with it. The ice just below the débris zone is coated with the finer materials washed down, and for this reason is melted back more rapidly than clean ice, and most rapidly where the coating is thickest. This causes the layer just below the débris zone to be melted back, on the whole, faster than the layer above, and to recede most rapidly at the débris level. This gives rise to the phenomena seen in Fig. 11.

Stratification and veining of the ice.—One of the conspicuous features of the ice of north Greenland is its distinct and often very conspicuous stratification (see Figs. 3–7 and 11), though there is much arrangement in layers which is not stratification, in the proper sense of the term. The layers (and veins) may be horizontal or vertical, or inclined at any angle. The arrangement of the vertical layers (veins) may be longitudinal or transverse, with reference to the glacier.

The presence of débris between the horizontal or approximately horizontal layers often helps to emphasize their distinctness, but their existence is not the result of the presence of débris. Certain layers of the ice are more solid (and blue), and certain other layers are more porous (and white). It is upon the varying texture of the different layers that the stratification in the upper part of a glacier is usually dependent, while the débris often emphasizes the distinctness of the layers in the lower portion. The horizontal layers or laminæ of ice are of variable thickness, and it would appear that the melting of ice, like the weathering of rock, often develops laminæ within layers which, in a firmer condition, appear massive. The number of laminæ is often as much as eight or ten to the inch, at the same time that layers several feet in thickness do not, in a solid con-

Fig. 8.—Edge of the local ice-cap on the peninsula between Bowdoin Bay and Inglefield Gulf. The low slope of the ice in the foreground is due to snow.

Fig. 9.—Edge of the local ice-cap north of Olriks Bay. The lower slope is snow.

dition, show conspicuous division. The horizontality of the layers is often interfered with at or near the ends of glaciers, and also at and near their lateral margins. This will be referred to later.

The vertical arrangement of layers appears to belong to the

FIG. 10.—Edge of a glacier on the southeast side of McCormick Bay, showing effect of débris on overhang.

category of veining, rather than stratification. The vertical veins appear to be altogether absent in many glaciers, and to be present in portions only of many others. Their presence or absence did not appear to depend upon any condition which affected the differentiated portion of the glacier. Indeed, if there are significant differences between the surroundings of glaciers which have vertical-longitudinal veins and those which have not, it was not discovered. The vertical-longitudinal veins were not seen in a

large proportion of the glaciers visited. Where present, they sometimes showed themselves on the surface of the ice, so that in crossing the glacier, lining parallel to its axis was conspicuous. The lining was often emphasized by the fact that certain

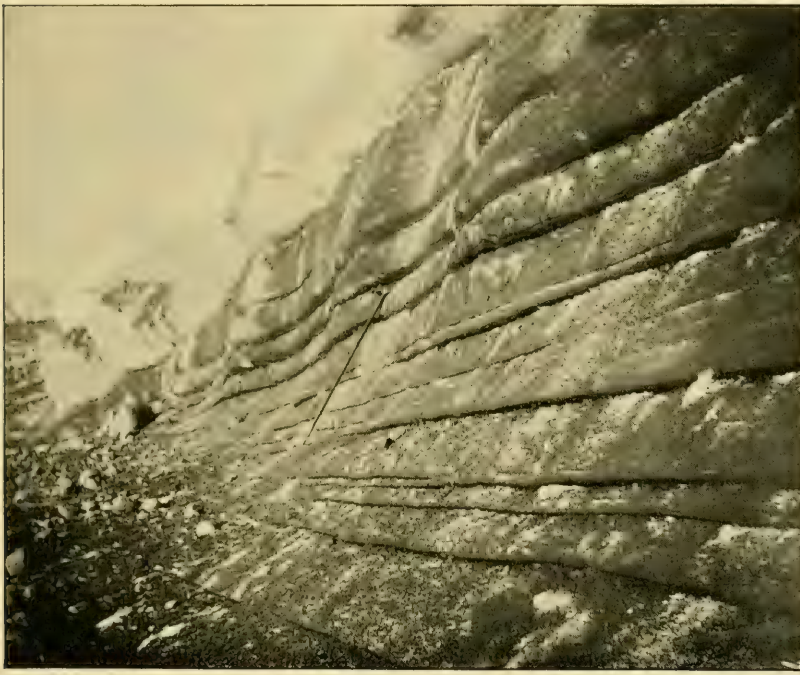

FIG. 11.—Edge of Tooktoo glacier, next a nunatak separating it from the Bowdoin glacier. A few miles above the head of Bowdoin Bay.

veins, presumably of less compact ice, melted more readily than others, thus developing grooves, between which the edges of the more resistant layers stood out as ridges. These vertical-longitudinal veins are of various thicknesses, but usually less than an inch. In some glaciers, notably in the western glacier of the north side of Herbert Island, there was a double ribbing of the surface, as shown in the accompanying diagram (Fig. 13). The larger swell or ridge, made up of many minor ones with their intervening grooves, seemed to be due, in some cases, to the

fact that the more solid veins composing it were thicker, and the less solid ones thinner, than in the troughs which lay beside them.

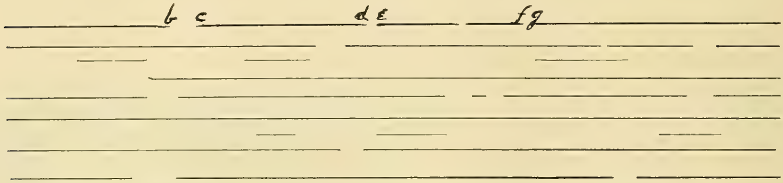

FIG. 12.—Diagrams showing how the overhangs, such as shown in Fig. 11, are interrupted laterally. The lines represent overhangs, and the interruptions represent the disappearance of the overhangs.

FIG. 13.— Diagram showing transverse profile of a small portion of the surface of the westernmost glacier on the north side of Herbert Island.

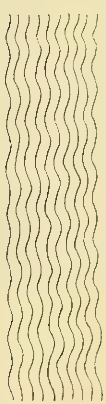

FIG. 14.—Diagram showing the wavy or sinuous course of the outcropping edge of longitudinal vertical laminæ. Same glacier as Fig. 13.

In some places these vertical ribbings on the surface were far from straight. Occasionally, as on one of the glaciers on Herbert Island, they were distinctly wavy, as shown in Fig. 14. In two cases the vertical veining was seen at the ends of glaciers, where their faces were vertical. In these sections the outcropping edges of the veins were not straight in a vertical sense. Indeed they were sometimes sharply flexed.

Vertical veins transverse to the axis of the glacier, and therefore at right angles to the series just described, were seen in several places. They affect some glaciers where the longitudinal set is wanting, and some where it is present. The two sets of vertical veins may be in different portions of the same glacier, or they may affect the same part. Where seen, the longitudinal veins were thinner than the transverse, and more continuously present.

FIG. 15.—Contorted laminæ of ice in front of a lens of débris in the ice. Side of a glacier on the southeast side of McCormick Bay.

FIG. 16.—The other end of the same lens of débris as shown in Fig. 15.

The transverse veins appeared to belong to more than one category. In some cases they seemed very much like the longitudinal veins, while in other cases they seemed to be comparable to dikes. In places, these dike-like veins were as much as three or four feet thick. Locally they were of compact blue ice near their front and back walls, while the central portion was notably more granular. On the melting surface this resulted in a little ridge on either margin of the vein, with a slight depression in the center. Where a superglacial stream cut an ice gorge across one of these dike-like veins, it was often seen that the vein (or at least its walls) was of ice which was distinctly harder (and bluer) than that on either hand. As a result of its superior hardness, a rapids or waterfall was developed just below the vein, and there was a tendency to ponding above, just as in the case of a young stream cutting across a hard, vertical layer of rock. The transverse-vertical veins were nowhere seen to be contorted, or to present notably wavy outcrops at the surface.

Contortion of the layers and laminæ.— Professor Chamberlin has already called attention to the contortion of the laminæ in the Greenland ice. In the glaciers which I saw, contortion of laminæ seems to have been less general than in the glaciers seen by him. Indeed, most of the glaciers seen showed no considerable amount of contortion of laminæ, though in some cases the phenomenon was conspicuous. Its presence or absence seemed to be dependent upon certain relations, some of which at least were easily made out.

The horizontal laminæ are likely to be contorted about the considerable lenses or masses of débris which are occasionally incorporated in the body of the ice. This is shown in Fig. 15, which represents a frequently repeated relationship. Great masses or lenses of débris were rarely seen in the vertical face of a glacier, without contortion of laminæ, both behind and before, though the laminæ of ice above and below were not usually affected by contortion.

A second position in which the contortion of horizontal layers is common, is at the very base of the upper, clean part of the

FIG. 17.— The laminæ of ice in the upturned and thickened layers are somewhat contorted. Herbert Island.

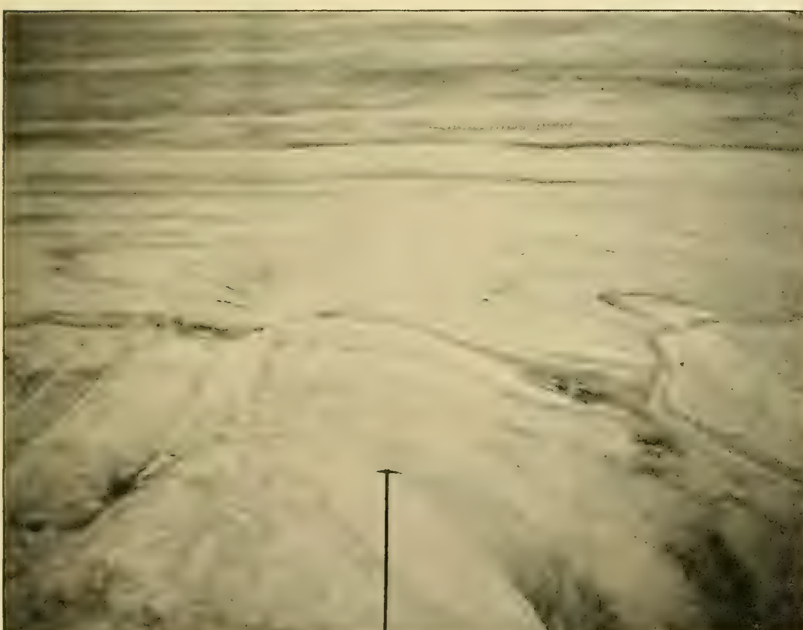

FIG. 18.— Contorted laminæ of clean or nearly clean ice. Glacier on the south side of Olriks Bay.

ice, just above its junction with the débris-charged portion below. In such cases, where a vertical section was exposed which really showed the structure of the ice, contortion was the almost universal rule.

In a few places the contortion of laminæ was seen to be

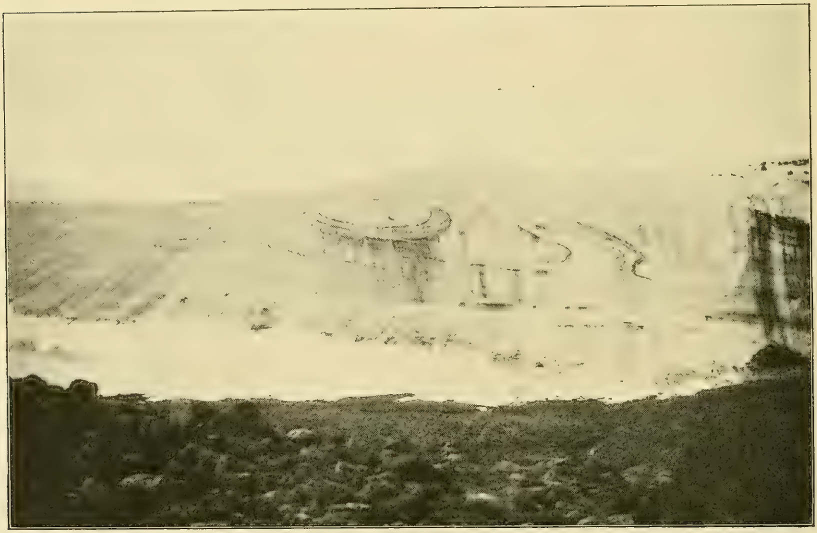

FIG. 19.— Structure resembling concretionary forms. Glacier on south side of Olriks Bay, west of the last.

striking where débris was absent, or where but little was present. This, however, is the exception rather than the rule (Figs. 17 and 18). Such a case is indicated in Fig. 6, which represents a sort of fœtal glacier — a tiny lobe projecting out from the edge of the ice-cap in the vicinity of Meteor Bay, some twenty-five or thirty miles northeast of Cape York. Attention is especially called to the position of the contortions, a position which is well-nigh universal. The bends are such as to suggest that the upper layers are crowding on faster than the lower. In a single case, only, were the contortions seen to lie in the opposite position, and this was on the opposite side of the same lobe.

The upturning of the layers of ice.—One of the striking phe-

nomena of the Greenland glaciers is the upturning of the horizontal layers at the ends and sides of glaciers. The upturning is most conspicuous as a rule at the extreme end. It becomes less and less striking with increasing distance from the end, and is not apparent at any considerable distance above. At the extreme ends of glaciers the upturning was seen to vary from a few degrees to verticality. An upturning of 30° or 40° was by no means uncommon. Higher inclinations were less frequent, and in but a single situation, namely in a glacier on the south of Olriks Bay (Figs. 20 and 21), was verticality attained. Figs. 20 and 21 represent a vertical face of ice at the end of a glacier, but the face is parallel to the axis of the glacier, not transverse to it. The same phenomenon in the same relations may frequently be seen at the sides of the glaciers. Fig. 22 shows the positions of the layers at the lateral margin of a glacier near Karnah. The layers are turned up most conspicuously at the extreme edges, and less and less markedly with increasing distance from them. So closely is the upturning confined to the lateral margins that the larger part of the surface of a glacier, even one where the lateral upturning is extreme, shows nothing of it. The upturning at the sides of a glacier is rarely equal to that at the end.

The lateral upturning is best seen at the vertical ends of glaciers. The following diagram (Fig. 23) may almost be said to represent the normal structure of a small glacier, as seen from its vertical end. If the glacier be a large one the structure shown is more likely to be that indicated diagrammatically in Fig. 24. The number of anticlines and synclines seen in cross-section in a large glacier may be several.

The upturning of the ends and edges of layers is not confined to differentiated glaciers, but affects the edge of the ice-cap as well. The edges of the main or local ice-caps were crossed in all at nine points. In seven of the nine, the marginal upturning of the layers was markedly developed. Generally speaking, it was most conspicuous where the visible amount of débris was greatest, and least where the débris was

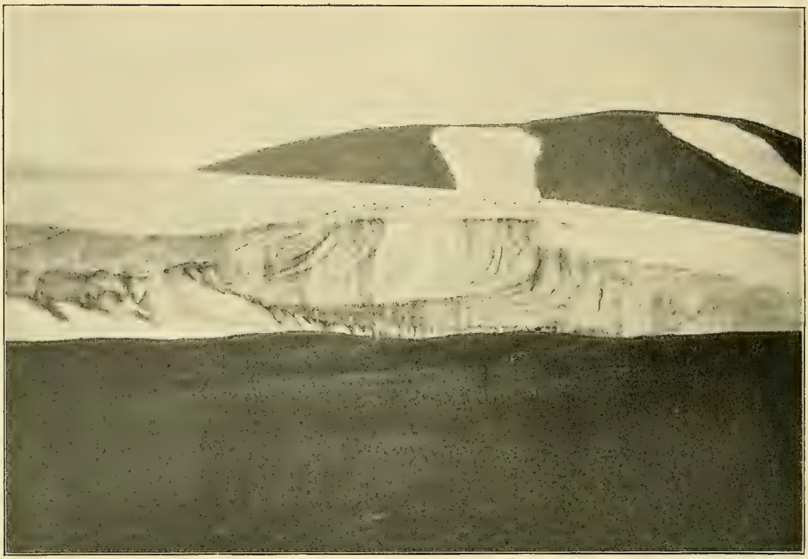

Fig. 20.—Vertical face of a glacier south side of Olriks Bay. The section is parallel with the axis of the glacier near the middle of its end. The dots on the surface are stones, lying along the outcropping edge of a layer.

Fig. 21.—Enlarged view of a portion of 20.

absent or meager. It was not always clear, however, which was cause and which effect. On the whole it seems probable that each helped the other.

FIG. 22.—Showing the inward dip of layers of ice at the side of a glacier on Redcliff peninsula, above the settlement of Karnah.

Upturning layers of ice and superglacial débris.—The upturning of the layers of ice at the ends and edges of glaciers is often made especially obtrusive by the existence of well-defined layers of débris between them. As the upturned edges are melted, the débris in or between them accumulates on the surface of the ice along the line of outcrop of the débris zone. A small

amount of débris is shown in Fig. 20 along the line where one of the upturned layers reaches the surface. Where the débris in or between upturning layers is abundant, it is often accumulated in large quantities on the surface of the ice along the line of outcrop of the débris-bearing layer. This seems to

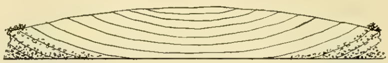

FIG. 23.—Diagram showing the structure of a small glacier as seen from its vertical end.

necessitate the conclusion that the drift is carried up to the surface by the upward movement of the upturned layers.

If the débris in a layer of ice, or between any two layers, were equal in amount at all points, it would appear at the surface in a continuous line or belt of drift, equal at all points. Its abundance would be dependent on the abundance of débris in the layer concerned, and on the length of time it had been bringing débris to the surface. In the course of time a very considerable ridge of drift might accumulate at the surface.

On the other hand, if the débris in or between layers of ice be more abundant at some points than at others, the accumulation on the surface would be in the form of an unequal, or possibly even a discontinuous ridge, more massive where the débris brought up is abundant, less massive where it is meager, and absent where it fails altogether. The same general rela-

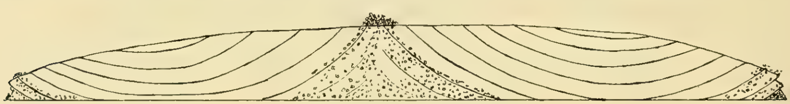

FIG. 24.—Diagrammatic representation of the structure of a large glacier as seen from its vertical end.

tions would hold concerning the upturning of the layers along the lateral margins of a glacier as along its end.

Phenomena illustrating these points were seen in many localities, both on the ice-cap itself, and on differentiated

glaciers. The edge of the ice-cap a few miles west of the upper end of Hubbard glacier showed the phenomena here referred to in simple form. Here the layers of ice at the edge of the ice-cap were upturned sharply. Between them, or between some

FIG. 25.—A ridge of superficial débris accumulated on the surface of the ice where an upturned layer reaches the surface. Edge of main ice-cap west of Hubbard glacier, Inglefield Gulf.

of them, there was débris, usually small in amount. The lines of outcrop of the débris-bearing zones were clearly marked on the surface of the ice-cap by nearly continuous lines of débris (Fig. 26). These lines were very unequal. The amount of drift coming up was much greater at some points than at others, and here the drift on the surface was piled up into very considerable mounds. Fig. 27 represents one of these mounds, something like thirty feet high, but it is probable that some portion of this elevation is due to a core of ice which is protected from melting by the drift which caps it.

Further west, and but a few miles east of Gable glacier,

where the main ice-sheet approaches the local ice-cap of the peninsula between Bowdoin Bay and Inglefield Gulf, the edge of the former shows similar phenomena on a much more extensive scale. Here drift comes up to the surface, not between all adjacent layers of ice, but only between certain layers. The

FIG. 26.—Belts of débris on the edge of the ice-cap west of Hubbard glacier. Each belt is confined strictly to the line of outcrop of an upturned débris-bearing layer.

larger part of it is in five distinct zones, which mark the outcrops of as many débris-charged horizons of ice. Each one of these belts of drift is irregular, here higher, there lower, so that each belt, instead of being a continuous and even-crested ridge of drift, is really a succession of mounds. Where the mounds attain considerable proportions, the drift spreads from their bases, so that high mounds are also always wide. Where two adjacent belts of drift are both irregular, it frequently happens that the mounds along one belt spread to such an extent that their bases are confluent with the bases of the mounds of the other belt.

These phenomena, repeated for all five belts of drift, gave rise to a peculiar and suggestive disposition of débris on the surface of the ice. Where the five belts approach each other so closely that the spreading drift of one becomes confluent with that of those adjacent, the surface of the ice for considerable areas

is completely concealed. Where this happens, the topography of the superficial drift reproduces, in all essential respects, the topography of the rough terminal moraines of the United States. Between adjacent hillocks or short ridges there are round, irregular, or elongate depressions, with sides often as steep as the

Fig. 27.—Mound of débris on edge of ice-cap near Hubbard glacier. It represents an exceptional accumulation of débris at one point, along the line where an upturning layer outcrops.

material will lie. The swells between the depressions are correspondingly abrupt. In its general contours, as well as in the specific relations of the elements of its topography, the surface drift of this locality is so like that of the terminal moraines of the United States as to suggest that, in the phenomena shown on the ice-cap at this and other points, is to be found the explanation of at least a part of the roughness of topography which characterizes terminal moraines in general. It is probably true that if the ice within the area here mentioned were to melt, depositing the drift on the surface beneath, its topography would be less rough than it is now, for it is probable that some considerable part of the elevations which appear to be of drift is really due to cores of concealed ice.

The phenomena shown on the ice-cap east of Gable glacier were shown to a less extent at various other points along the edge of the ice-cap in the vicinity of Inglefield Gulf, but best of all in the vicinity of Uminooi, latitude 76° 30′ (approximately). Here the edge of the main ice-cap was seen where there were eight of these marginal ridges of drift on the ice, sometimes separated by intervals of twenty or thirty rods, sometimes closely approaching each other. They were all gathered within a narrow marginal zone, the inner edge of which was not more than half a mile from the edge of the ice. The higher the angle of slope of the ice, the more closely did the belts of drift approach each other; the gentler the slope, the more widely were they separated. As in the locality north of Inglefield Gulf, each of these belts of drift was exceedingly irregular, being made up of a succession of hillocks, and short, or sometimes rather long, ridges, between which were depressions. Three of the depressions seen in this locality contained ponds or lakelets, one of which was fully 200 yards across. The existence of ponds in the depressions in the surface of the superglacial drift tended still further to emphasize the likeness of its topography to the topography of terminal moraines.

In this locality a single superglacial stream was found cutting through some of the belts of drift in such wise as to expose a shallow, though otherwise perfect section of the upper part of the ice below one of the belts of drift. The phenomena shown in the sides of the the little gorge are illustrated by the accompanying diagram (Fig. 28). The layers of ice beneath the drift turned up abruptly. In their upturning and movement they had brought débris to the surface, and as the ice melted this débris had accumulated on the surface, forming a ridge of drift. This ridge of drift had protected the ice beneath from melting, so that the upturned layers of ice, apart from the drift, constituted a diminutive ridge. That there was upward movement of the highly inclined layers seemed certain, not only from the relations of the débris, but from the bending of the adjacent horizontal layers.

The juxtaposition of the highly inclined and approximately horizontal layers, as shown in the figure, is explained as follows: In recent years the snow fall has exceeded the melting. Of this there was abundant evidence. Just before this condition of

FIG. 28. Diagram showing longitudinal section of ice, as shown in the wall of the canyon of a superficial stream where the latter crossed a surface moraine.

things came about, melting had exceeded accumulation. The surface of the ice had been lowered, but the drift had protected the ice immediately beneath it, so as to give origin to a low ice ridge beneath the drift along the line of débris. It is believed that, at this stage, all the layers of ice near the edge of the ice-sheet were upturned, as they are now believed to be a little below the surface. The theoretical condition of things before the heavy snows of recent years is illustrated by Fig. 29. Later, when the snow fall exceeded the melting, the falling and accumulating snow was transformed into horizontal, or nearly horizontal, layers of ice (or névé), where it rested on ice. The drift, because of its heat absorbing qualities, helped to melt the snow which fell upon it, and its surface being elevated above that on either hand, allowed the snow to be blown off more than from the surrounding surface.

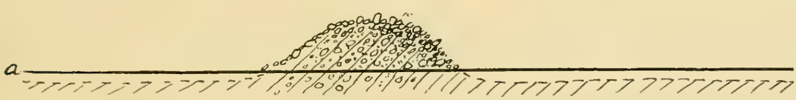

FIG. 29. Hypothetical profile of surface of Fig. 28 before the development of the overlying horizontal layers.

The drift phenomena shown on the edge of the ice-cap in association with the upturned layers, was repeated in many cases on glaciers, on the surfaces of which the upturning layers of ice had given origin to irregular and discontinuous ridges of drift.

These ridges were always near the ends of glaciers, and usually concentric with their termini, where the termini were not cut off by the waves. The surface ridges of débris, concentric with the ends of glaciers, were especially conspicuous on some of the glaciers on the north side of Northumberland Island, and on the glacier at the head of Dexterity Harbor, on the west side of Baffin Bay (Lat. 72°).

The making of lateral moraines.—Many of the North Greenland glaciers carry lateral moraines, the explanation of which is certainly to be found along the lines just indicated. In general the lateral margins of the glaciers do not touch the sides of the valleys in which they lie. Indeed they are generally separated from them by distinct intervals, and this holds well up to the heads of the glaciers. Within the stretch where the lateral margins of the glaciers do not touch the valley walls, lateral moraines have their least development near the heads of glaciers, where they are often absent, and their greatest near their lower ends. The lateral moraines, therefore, could not have been formed by the falling of débris from the valley slopes onto the ice, for of this there is no possibility. The upturning layers, as seen in cross-section, and the débris seen between these layers (Fig. 23), seem to show conclusively that the lateral moraines were formed by having material brought to the surface by the upturning and up-moving layers of ice. In some cases three of these lateral moraines lay side by side near the margin of a glacier, though more than two were rare. This statement is not to be construed to mean that this is the only way in which lateral moraines are made, but it seemed to be the prevalent way in the case of the glaciers seen in north Greenland.

Glacier load and its relations to movement.—Professor Russell[1] has called attention to the fact that the movement of ice is influenced by the amount of débris which it carries. This doctrine finds abundant confirmation in the north. The lower part of the ice, which is well charged with débris, or altogether full of it, seems to virtually lose its motion and to become the

[1] This JOURNAL, Vol. III, p. 823.

bed over which the upper ice passes. It is not possible to say that its motion is absolutely lost, but many phenomena seem to make it certain that the upper portion of the ice of a glacier passes over the lower débris-charged portion in the same way

FIG. 30.—End of a glacier on southeast side of McCormick Bay, resting on its embankment.

that it passes over a rock bed. The lower part of the ice in such cases becomes virtually an ice conglomerate, the mobility of which is certainly slight.

Morainic embankments.—The ends of many of the north Greenland glaciers appear to rest on huge embankments (or pedestals, as Chamberlin has called them) of drift, which they have constructed for themselves. The phenomenon is shown in Fig. 30. In reality these pedestals or embankments of drift on which the ends of many of the glaciers seem to rest, are less extensive than they seem. In many cases they appear to be 100

or 200 feet high, and, in extreme cases, as much as 300 feet. In the case of several glaciers, however, phenomena were seen which seem to throw doubt on the conclusion which at first sight seemed obvious. Where considerable streams plunge over the vertical faces of the glaciers, and cut gorges in this apparent embankment, it is now and then seen that the embankment is, after all, not composed entirely of drift, but that it is really glacier ice so full of débris that it has practically lost its motion, and that its outer surface only is coated with drift, free from ice. It is readily seen how this coating would be a necessity. As the débris-charged ice melts on the exterior, the débris which it held is loosened, and if the face of the ice be steep, slides down and comes to rest at such an angle as it is capable of assuming. If this process be carried on for a long period of time, the result is such as to give the impression of a great morainic embankment, when in reality much of the apparent embankment is ice, full of débris. In some sense, however, it is not wrong to look upon this apparent embankment of drift as really such, for were the ice in it to melt, a great embankment would still remain, but little less in height in some cases than it now appears; for the ice is often so full of débris that it comes to occupy only the interspaces between the stones and sand grains, and melting would not allow the drift to settle together to such an extent as to greatly diminish the height of the apparent embankment.

This conclusion is confirmed by phenomena seen at several points. In some cases small glaciers which had the habit of making these terminal embankments have disappeared or retreated, and the embankments which they had constructed, remain. This is shown in Fig. 31, which represents the morainic embankment left by an extinct cliff glacier[1] on the north side of Herbert Island. Several similar embankments occur in the same region.

In no case was the total apparent embankment determined to be of ice-filled débris, but in one place glacier ice was seen 110 feet below the apparent top of the embankment, so that the

[1] For definition of cliff glaciers, see this JOURNAL, Vol. III, p. 888.

glacier ice certainly extended that far down into the débris. The ice seen at this point, and in other gorges in similar situations, was distinctly laminated or stratified, and the laminæ were much contorted, just as in the case of glacier ice. This is

FIG. 31.—A morainic embankment, left at the terminus of an extinct cliff glacier, north side of Herbert Island.

mentioned only as indicating that the ice which cements the débris is not ice formed by the freezing of water which has trickled down from above into the débris, though in some cases this may be the fact.

It is evident that the growth of an embankment would be chiefly at the very terminus of a glacier. It is here that advance motion ceases, and it is here that all the material brought down from above must stop. It is easy to see that the débris, or débris-filled ice (which for present purposes amounts to the same thing) under the end of the active ice, might easily become higher than the bed of the glacier above. The ice would then have to push the embankment forward, or rise up over it. This probably has something to do with the upturning of

the terminal layers of ice. The same explanation would apply to the lateral margins of a glacier, where the upturning, so far as due to this factor, should be less than at the end, as is the fact.

Superglacial material.— Apart from the débris which gathers on the surface of glaciers near their ends and edges, and apart from that which gathers on the surface of the ice-cap near its edge, superglacial drift is generally wanting on the Greenland ice. Except in situations just below nunataks, stony débris was not seen at any point on the surface of the Greenland ice-caps, whether main or local, more than a fraction (rarely so much as one-fourth) of a mile back from their edges. On the surface of differentiated glaciers débris was often seen on the surface farther back from their ends, but this, in general, was in the form of medial moraines, marking the approximate line of contact between confluent glaciers, or representing material derived from nunataks, or from elevations which projected well up into the ice, but not through it, and therefore did not constitute nunataks. Occasionally there was débris in the form of medial moraines along the anticlinal part of the structure of the ice, as shown in Fig. 24.

At the very edges of the ice-sheets, and at the ends and edges of the glaciers, and in the position of medial moraines, superglacial drift was abundant, but apart from these situations there was no superficial drift on either ice-caps or glaciers, except the small amount of dust which had reached its position by the help of the wind. The wind-blown dust diminishes in quantity with increasing distance from the edge of the ice-cap, and from the ends and edges of glaciers. It is generally inconspicuous a mile or two back from the edge of an ice-cap, and inconspicuous on glaciers at any point as much as two or three miles from the nearest land surface.

That the dust was of wind origin could not be doubted, since it was absolutely free from all material which might not be readily transported by the wind, and did not affect the ice except at its surface. Furthermore, it contained, not infre-

quently, the leaves and twigs of the little shrubs which grow on the land in the vicinity.

The general absence of superglacial material on the ice-caps and glaciers of Greenland, except in situations in which débris has always been known to occur on glaciers, would seem to put an end to the doctrine which has been given currency in certain quarters that glacial débris in large quantities rises through the ice and gets upon its surface; for if the ice-cap of Greenland is free from superficial débris — except at its very margin — it would seem that the same should be still more conspicuously true of an ice-sheet on a plainer country, like our own. It is believed, however, that the phenomenon of the upturning of the layers of the ice at the edge of an ice-sheet would hold in a flat region, as well as in a mountainous one, especially where the ice was well charged with débris in its lower parts, and that this upturning would give rise to superficial drift for a few yards, or possibly a few hundred yards, back from the edge of the ice.

The disappearance of the doctrine of superglacial drift, as a general phenomenon, carries with it, of necessity, the doctrine that kames and eskers are the product of superglacial waters. On this point it should be further said that hundreds of superglacial streams, long and short, were seen on the ice-cap and on the glaciers of North Greenland, and with a single exception there was no material whatsoever accumulating in their channels. Except within the limits noted there was no drift upon the ice which the surface streams could not get hold of, nor, except at its very margins, was there drift in the ice down to the level to which the streams cut. Furthermore, the streams are almost uniformly so swift that no drift could accumulate in their channels unless it were extremely abundant on the surface. Every considerable stream seen on the ice had so high a velocity, and so smooth a bed, that even bowlders of considerable size would have been hurried along it precipitately, had they once entered the channel.

In the single case in which débris was seen in a superglacial stream channel, the amount was small and the conditions pecul-

iar. The stream was within a quarter of a mile of the edge of the ice, and flowing over the upturned edges of unequally hard layers of ice, which in their upturning had brought abundant débris to the surface. The harder layers stood up as little ridges, ponding the water above them and producing rapids below. In this stream there were trivial patches of gravel in the ponded portions. Even here there was nothing to suggest the development of an esker or a kame. There seems, therefore, to be no warrant in the phenomena of North Greenland, so far as known, for the belief either that there is, or can be, much superglacial till, or that superglacial streams can do much in the way of depositing stratified drift.

Physical and chemical condition of superglacial material.—The statement has often been made that superglacial material is highly oxidized and weathered, and that, on the basis of these characteristics, it may be distinguished from subglacial material, even in the drift deposits of the United States. This has been repeatedly cited as a criterion for the recognition of superglacial drift. This point was in mind during the study of the glacial phenomena of Greenland, and it may be emphatically stated that the superglacial drift of that land is not noticeably more oxidized and weathered than the subglacial. Where superglacial drift occurs, it appears to be as fresh,and its elements as firm in every way, as the subglacial material to be seen but a few rods away.

Lack of wear has been thought to be a mark of superglacial, as distinct from subglacial, bowlders. But the superglacial drift seen was often, though not always, as distinctly and thoroughly worn as the subglacial. This never appeared to be true where the superficial material arose from a nunatak, or from a hill or a mountain which just failed of being a nunatak, but it was generally true where the material on the surface had been brought up from the bottom by the upturning layers.

Glacial drainage.— Another striking feature of the north Greenland glaciers is the fact that the drainage from them does not behave altogether as drainage from glaciers is commonly supposed to. In the first place it is the rare exception that a

visible stream of any size issues from beneath a glacier at its end. That water really issues from the end of the glacier and flows on beyond can hardly be doubted, but in general it escapes beneath or through débris, rather than over it. In some cases, indeed, in crossing the embankment slope in front of the end of a glacier the motion of the water in the drift beneath one's feet can be heard.

As before noted, the sides of a glacier rarely rest against the valley in which the ice-stream lies, and in the gorge between the ice on the one side, and the valley wall on the other, there is usually a stream. These lateral streams are tolerably constant accompaniments of the glaciers, as Chamberlin has already pointed out.

Surface ablation does not give rise to many considerable streams on the surface of the ice. The surface is usually so crevassed that the water plunges beneath it soon after its formation, and the stream which continues for more than a few rods on the surface is the exception rather than the rule. Cases were however seen where superficial streams were continuous for some miles. The longest seen was on the surface of the largest glacier on the north side of Herbert Island. Here, in the summer of 1895, a stream was essentially continuous from the head of the differentiated portion of the glacier to a point near its terminus.

Englacial drainage does not show itself so long as the drainage is englacial, but the fact of englacial drainage was shown at several points. The most conspicuous example seen is shown in the accompanying figure, which represents the end of a large glacier on the south side of Olriks Bay. Here, as will be seen, a huge spout of water issued from about the middle of the vertical face at the end of the glacier. The diameter of the stream as it issued from the ice was about five feet. Issuing approximately horizontally, it showed that there was an englacial stream of similar proportions behind it. In such a case there is of course no means of knowing the length of the englacial stream, or how nearly it maintains its horizontal position. The

force with which the water shot out, in this particular instance. indicated plainly enough that it was under great head. In this case the stream was very red, due to the fact that it contained much sediment, or rock flour, arising from the comminution

FIG. 32. End of the large glacier on the south side of Olriks Bay. Englacial stream issuing.

of the red rock over which the ice had moved. Since the stream issued from the ice at a level quite above any considerable amount of débris, it would appear that somewhere in its course the water must have been at a relatively lower level in the ice, flowing, throughout a portion of its course, sufficiently near the bottom of the glacier to acquire the silt which it contained.

That englacial water sometimes does flow under great pressure was shown by a phenomenon seen on one of the glaciers near Godhavn on the island of Disco. Here from the upper

surface of the glacier there welled up a huge spring (Fig. 33). The water shot up not less than ten feet above the bottom of the basin whence it issued. The water was intensely red, owing to the presence of the flour of red rock which the ice had ground

FIG. 33. Spring on the first glacier in the valley above Godhavn, Disco.

up. The upper part of the ice was nearly free from débris, and the water must have risen from a lower horizon in the ice. The inconstant character of englacial drainage is shown by the fact that two months later, at the same site, there was no suggestion of a spring. The water had found some other avenue of escape, though the basin and the opening in its bottom were easily found. The opening was about five feet in diameter, and for a distance descended nearly vertically.

Kames and eskers.—No esker was seen in Greenland, nor was any process observed which would at any time result in the formation of an esker.

Except in one situation, namely, on the north side of Olriks Bay, no kame was seen. Here there were some kame-like hills on a surface which had been abandoned by the ice, but no process was seen in operation along the margin of the ice at any point which seemed to throw special light on the origin of this class of drift hills.

The surface over which the ice has retreated.—In a number of places, surfaces were seen which have been, within relatively

recent times, covered by the ice, but which are now free from it. Such surfaces were seen on the Redcliff peninsula, and on the peninsula east of Bowdoin Bay; but in no case where the abandoned surface was seen did it appear to be true that its topography was fashioned by the drift. The main features, at least where there were roughnesses, seemed to be due to the underlying rock, and the effect of the drift, on the whole, was rather to level the surface than to roughen it. In general the topography of the drift on surfaces abandoned by ice-sheets, so far as it could be differentiated from the topography of the underlying rock, was nearly plane.

There were, however, minor details of surface which were notable. It was frequently to be seen that the drift of a surface recently abandoned by the ice was disposed in a multitude of tiny crescentic ridges, concave toward the ice. The ridges were one to ten feet wide, and one to ten yards long. They were generally no more than one or two feet high, and just within the crescent there was likely to be a depression of perhaps an equal amount, so that the generally flat surface still had a relief of two to four feet. This was perhaps the most conspicuous minor detail observable on the surface of the drift. Much of the drift-covered surface of the flat uplands looked as if a heavy roller had been passed over it. Much of the surface which had been recently freed from ice was essentially without relief.

On the whole, the drift in Greenland is notably more stony than the drift of our own country. Clay, due to the grinding of the rock, was everywhere conspicuous by its paucity or absence.

Rollin D. Salisbury.

THE GENESIS OF LAKE AGASSIZ.[1]

In a paper read before the Geological Society of America on December 28, last, entitled *The Relation between Ice-Lobes South from the Wisconsin Driftless Area*, Mr. Frank Leverett[2] appears to have made some very interesting records of the relative ages of the sheets of drift in Illinois and vicinity. As these are directly in line with the observations made by me during the past few years in Manitoba, and throughout the country northward lying west of Hudson Bay, a few notes on the conclusions to which these observations tend may be of interest in advance of the publication of my detailed reports and maps by the Geological Survey of Canada.

In a short paper published in the *Geological Magazine* for September 1894, based on the explorations of 1892 and 1893, the writer outlined the existence, during the Glacial Period, of a great glacial center or gathering ground lying comparatively close to the west coast of Hudson Bay, from which the ice radiated in all directions; eastward into the basin of Hudson Bay, which was probably an open body of water then as it is now, and furnished the moisture for the immense precipitation of snow a short distance to the west of it; southward towards Manitoba and the Great Plains; westward towards the Athabasca-Mackenzie Valley and the Rocky Mountains; northwestward and northward[3] toward the Arctic Ocean.

A second expedition by the writer through the same or adjoining country in 1894 served to corroborate and strengthen the conclusions reached in the preceding years. At or near the

[1] Published by permission of the Director of the Geological Survey of Canada.

[2] Abstract in American Geologist, February 1896, p. 102.

[3] Notes to accompany a Geological Map of the Northern portion of the Dominion of Canada, by GEORGE M. DAWSON, Ann. Rep. Geol. Sur. Can., Vol. II, 1886, Part R. p. 57.

center of glaciation the striæ were found to be very indefinite, and to have changed in direction as the center slightly shifted its position, but no evidence of any other general glaciation could be found, or that the ice had left the country uncovered from the beginning to the close of the Glacial Epoch.

In the *Geographical Journal* for November 1895, p. 439, I have used the name Keewatin glacier for this continental ice-sheet, as its center lay in the northern portions of the District of Keewatin, and I shall continue to use that name, with the understanding that if it prove to be the same as the ice-sheet of the Kansan or Iowan period it will give place to one of these prior names unless indeed both of the latter should be found to represent re-advances of the same glacier, in which case the name "Keewatin" might conveniently be retained. At the same time I would suggest that Dr. Dawson's name "Laurentide Glacier" be restricted to that great *mer de glace* centering over the country north of the St. Lawrence River and the heights of Labrador.

A portion of the former glacier, advancing southward or southwestward, came in contact with the high escarpment of Cretaceous shales in western Manitoba, and by it was diverted more to the eastward, taking the trend of the great valley of Lake Winnipeg and the Red River. In this direction it appears to have advanced far into Minnesota, Dakota, and Iowa. The Palæozoic limestones of western Manitoba are beautifully scored by its markings, and its grooves and striæ were detected in many places as far east as the east side of Lake Winnipeg. East of Lake Winnipeg the exposed surfaces of the Archæan rocks were carefully searched for this set of markings, but none could be detected. It therefore seems probable that the eastern edge of this lobe or portion of the Keewatin glacier did not extend very far east of the present eastern shore of Lake Winnipeg, and it is also probable that throughout its advance there was a free drainage eastward, probably into Hudson Bay.

Traces of the existence of the streams that flowed eastward from the face or side of this glacier were found in several places in the form of deep pot-holes excavated in the summits or on

the eastern slopes of knolls of granite and gneiss, where they could not have been formed by the present streams or by others, like them, flowing westward. At one place, on the south side of Berens River, several of these pot-holes occur on the east side of a granite knoll, one of them, at least, being ten feet in depth, and about thirty inches in diameter from top to bottom. On the same side of the knoll, facing up the present stream, was a well-marked water-worn groove, leading down to a shallow pot-hole at the foot of the hill. The ten-foot hole was cleaned out and was found to contain a great number of well-rounded pebbles, all of Archæan rocks, some similar to the rocks of the surrounding country and others that had evidently been transported from a distance. Both this and the other rocky hills where the pot-holes were seen have been eroded and scored by the later glacier from the east, the outer sides of some of the holes having been cut away, leaving rounded niches in the faces of the smooth hillsides.

After occupying the basin of Lake Winnipeg and the Red River Valley for an uncertain but doubtless long period of time, the Keewatin glacier began gradually to retire. As it retired a portion of the Laurentide glacier, which in the meantime had been accumulating in the country farther east, perhaps in the high land of the Labrador peninsula, gradually advanced. The Keewatin glacier seems to have retired northward well into Manitoba, and possibly even beyond the northern limit of that province, before it was joined by the eastern glacier. When they united the water was ponded between the fronts of the two glaciers to the north and east, and the high land to the south and west. Thus Lake Agassiz had its beginning. Its waters rapidly rose until they overflowed southward into the valley of the Mississippi and then gradually declined as the river Warren deepened its channel.

After the union of the two glaciers the Keewatin glacier may have remained stationary for a considerable period, during which time the strong ridge extending from Long Point westward between Cedar and Winnipegosis lakes and beyond, apparently

crossing the Saskatchewan River at the Pas, was formed in the bed of this lake.

Meanwhile the eastern glacier was advancing towards its extreme western limit near the west shore of Lake Winnipeg, for it never crossed the belt of land intervening between that lake and lakes Manitoba and Winnipegosis. Before it reached the mouth of the Saskatchewan River, on the west side of this lake, the Keewatin glacier had already retired a considerable distance farther north, a sufficient time having elapsed to permit of the deposition in the bed of the lake of at least twelve feet of thinly and evenly stratified sands and clays over till of the earlier glacier, before they were covered by the till of the later glacier. The section of these two tills, with the intermediate stratified deposits, is well exposed on the bank of the Saskatchewan River near its mouth, and has been described by the writer in his "Report on Northwestern Manitoba."[1]

The later history of Lake Agassiz has not yet been definitely determined, but it would seem reasonably certain that the Keewatin glacier continued to retire northward until it separated from the eastern glacier. Then the water would drain freely around the northern end of the latter glacier to Hudson Bay. The northeastern drainage has been shown by Mr. Upham[2] to have begun at the level of the Blanchard Beaches, the highest of which, along the line of the Manitoba and Northwestern Railway, is stated to be at an elevation of 994 feet above the sea or 284 above the present level of Lake Winnipeg. The eastern glacier seems to have now begun to retire, and its front had retired to a short distance east of the east shore of Lake Winnipeg when the Burnside and Gladstone Beaches were formed at elevations of from 150 to 170 feet above the present lake. Stratified Lake Agassiz sands and clays were deposited in considerable thickness on this side of the lake up to the above level, apparently near the front of the glacier. That the eastern glacier

[1] Ann. Rep. Geol. Sur. Can., Vol. V, 1890–1, Ottawa 1893, Part E, p. 146.

[2] Report of Exploration of the Glacial Lake Agassiz in Manitoba, by WARREN UPHAM, Ann. Rep. Geol. Sur. Can., Vol. IV, 1888–9, Part E.

had not retired further east during the time when Lake Agassiz stood at a higher level is shown by the absence of stratified lacustral deposits above the 150–170-foot line, in many places only a very few miles from Lake Winnipeg, an absence peculiarly noticeable as these deposits occur in such abundance below that line.

It is thus seen that the Keewatin glacier, which centered west of the northern part of Hudson Bay, had extended southward to its furthest limit, and had then retired many hundreds of miles, probably more than half way to its gathering ground, before the Laurentide glacier had reached its greatest extension.

Dr. Dawson[1] has also shown that the Cordilleran glacier reached its greatest extent and retired before bowlder-clay that generally underlies the western plains was deposited. This bowlder-clay I take to be the true till or ground moraine of the Keewatin glacier, when this glacier had reached its greatest extent in a southwesterly direction.

The evidence at present at hand would therefore seem to strengthen the view that in the northern part of this continent during the glacial period there were three great centers of snow and ice accumulation, one, the Cordilleran in the mountains of British Columbia, a second, the Keewatin, on the comparatively low land northwest of Hudson Bay, a third, the Laurentide, in the Labrador Peninsula.

Beginning at the west, and going eastward, these three great glaciers would seem to have reached their widest extent and retired in succession. Still further east, across Davis Straits, a fourth great glacier, probably similar in character to those that have disappeared from the American continent, covers Greenland at the present time.

J. BURR TYRRELL.

[1] Glacial Deposits of Southwestern Alberta, in the vicinity of the Rocky Mountains, by GEORGE M. DAWSON, Bull. Geol. Sur. Am., Vol. VII, pp. 31–66. Nov. 1895.

LACCOLITES IN SOUTHEASTERN COLORADO.[1]

THE western part of Colorado is mountainous; the eastern belongs to the Great Plains. The plains are in part smooth, as the name implies, and in part broken by canyons and diversified by valleys, cliffs, and terraces. Near the southeast corner of the state is a broad upland plain, bounded on the north, south, and west by bluffs that overlook lowlands with diversified relief. The plain slopes gently toward the east and is furrowed here and there by streams flowing in the same direction. Its determining formation is an alluvial deposit of sand and gravel, believed to be of Neocene Age. This rests on an eroded surface of Cretaceous and Juratrias rocks, and these rocks are exposed in the surrounding lowlands as well as in the channels of the dissecting streams.

Previous to the modern dissection the alluvial plain must have been remarkably even, but a few knobs of resistant rock projected above it, and one of these now stands so high as to constitute a conspicuous landmark. Twin Butte, or Two Buttes as it is sometimes less aptly called, is conical in its general form but has a double summit. Past its southern base flows Two Butte Creek, and the rock exposures are continuous from the butte to the creek. The crest of the butte is 350 feet above the plain and 600 feet above the creek. It stands in west longitude 102° 33′ and north latitude 37° 39′.

Visiting the locality in September 1895, I found the butte to be capped by a block of sandstone which had acquired exceptional hardness through association with a local occurrence of igneous rocks; and a hasty examination of neighboring exposures discovered such an arching of the Mesozoic strata as to

[1] The observations here communicated were made in connection with field work of the U. S. Geological Survey, and are published by permission of the director.

Proof of this article has not been read by the author.—ED.

indicate the presence of laccolites of some magnitude. The following month I returned to the locality in company with Mr. F. H. Newell, and we spent a week in local surveys and studies. A contour map of the locality was made, the thicknesses of the sedimentary formations were measured, and all outcrops were platted. By combining these data it was found possible to construct an approximate contour map of the deformation of the upper strata, and thus estimate the total volume of the intrusions.

The following is the sedimentary section as determined by Mr. Newell :

5. Olive, purple, and pink shales, with beds of fine-grained yellow sandstone, and one or more bands of concretionary impure limestone. The sandstone contains large, beach-rolled, silicified logs. From the upper shaly layers were obtained invertebrate fossils, recognized by Mr. T. W. Stanton as of Dakota age. The top of the formation was not seen, - - - - - - - - 100 ft.

4. Sandstone, fine-grained, chiefly massive but partly bedded, of variable color. On the east side of the dome all zones of the sandstone are bright red, and this is probably their normal color; but the different layers, as they approach the base of the Neocene sands, become yellow, and in some places white. On the southwestern slope of the dome, a shale forty or fifty feet thick parts the sandstone into two groups, of which the lower retains the characters just described, while the higher has a prevailing dull yellow color, and is in part vitreous, as though modified by igneous intrusion. A similar distinction was seen at the north, where most of the upper member has the character of quartzite, and the yellow color is replaced by gray, - - - - - - - 380 ft.

3. Brick-red shales, arenaceous at top and passing by gradual transition into No. 4. Soft and easily eroded, except in the immediate vicinity of igneous masses, - - - - - - - 150 ft.

2. White limestone, - - - - - - - - - 5 to 10 ft.

1. Yellow, red, and orange, thin-bedded shales and sandstones. The shales probably exceed the sandstones in thickness, but being largely arenaceous, they assume the character of sandstones in the vicinity of igneous intrusions. The bottom of the series was not seen, - - - - - - - - - - - 100 ft.

Total, - - - - - - - - - - 740 ft.

No fossils were found below No. 5, and our present knowledge of the general stratigraphy of the surrounding country does not warrant a definite correlation of the formations. A few miles farther north the Dakota formation is exposed in a broad belt, beyond which it dips under the Benton shales.

Two Butte Creek, which in general has a comparatively open valley, passes at this point through a box canyon sixty feet deep, and in the walls of the canyon the three highest formations are seen to arch regularly from west to east. They are also seen to dip southward, so that the structure revealed by the canyon is essentially part of a quaquaversal arch. Scattering outcrops of various formations at the north accord with this theory, and further confirmation is found in the vicinity of the butte, where some of the highest ground, excepting the butte itself, is occupied by the lowest formation, No. 1. The white limestone (2), which outcrops in the creek valley with southerly dip, is also found at the southeastern base of the butte, where it is nearly level; and the crest of the butte consists of the lower division of the red sandstone (4) which there dips to the west. By combining the stratigraphic and hypsometric data it was found possible to estimate at many points on the sheet the height to which the upper formations had been lifted; and with further aid from observed dips, contour lines were drawn to represent the figure of deformation. These contours appear in Fig. 5, where a distinction has been made between the parts practically fixed by the observed data and other parts interpolated with a free hand. So many minor inflections were found in the district exposed to direct study that we may suppose the actual contours to be much less regular than those supplied for the regions covered by the Neocene sands. At several points there are local flexures, giving dips of fifteen or twenty degrees, and it is probable that a fault traverses the western slope of the butte.

The formation thus determined has a basal breadth in any direction of from five to five and a half miles. Its central height is from 1000 to 1200 feet, the smaller estimate being derived from the northwestern slope, the greater from the eastern

and southeastern slopes. In neighboring regions the Cretaceous formations are characterized by flexures and dislocations of minor importance, and it is probable that a deformation of that general character is here combined with the arching due to igneous intrusion. A computation based on the contours of deformation indicates the total volume of the uplifted or protuberant mass as a little less than one cubic mile.

The igneous rocks associated with this local uplift include laccolites and dikes. There are at least two laccolites, and the number may be much larger. The highest is known only by a remnant exposed at various points about the southeastern base of Twin Butte, where it rests on the white limestone (formation 2) and is covered by red shale (3). It does not appear on other sides of the butte, and it is probably limited on the west by a fault. The steep westward dip of the overlying strata suggests that the mass may originally have been large. Beneath it, and separated only by the white limestone, is a broad mass whose upper parts only are seen. Its outcrop is nearly continuous for three-fourths of a mile from north to south and more than half a mile from east to west. Wherever its relations to the sedimentaries are seen it passes beneath them, the overlying strata being either formation 2 or some member of formation 1. South of this area is a smaller tract of igneous rock which may represent a laccolite or a sill; and beyond it is the irregular exposure of an intrusive mass which ranges in thickness from fifteen or twenty to more than 100 feet and traverses the formation obliquely so as to be walled in places by formations 1, 2, and 3. It is possible that the larger of the observed laccolite masses is the principal intrusion, occupying practically the whole interior of the dome; but consideration of the irregularities of the deformation leads rather to the view that the arch includes a number of individual masses.

About fifty dikes were noted traversing parts of the dome, and it is probable that others intersect the laccolites. One dike was seen at a point two miles beyond the northwest base of the dome, and at another point outside the dome a well sunk through

the Neocene sand brought up igneous rock of the same general type. The majority of the dikes trend approximately at right angles to the strike, so that if produced they would pass near the center of the uplift ; but on the southwestern slope of the dome a small group trend approximately with the strike.

In the various characters thus far mentioned the Twin Butte laccolites do not differ from the ordinary type, but petrographically they are rather exceptional, and their peculiarity of rock type is the occasion of geomorphic characters which are equally notable.

Classifying igneous rocks broadly as basic, intermediate, and acid, most of the laccolitic rocks heretofore described belong to the intermediate group, a smaller number are acid, and basic examples are comparatively unknown. R. C. Hills characterizes as doleritic two small masses observed in Huerfano Park, Colorado,[1] and Weed and Pirsson have described large laccolitic masses, occurring in the Highwood, Little Belt, and Bearpaw mountains of Montana, in which the outer parts are basic and the inner acid.[2] The Twin Butte rocks also are basic and closely resemble some of the Montana types. As the chief mass is so little dissected that all collections were from the upper part, it is quite possible that the new locality belongs structurally with the type discovered by Weed and Pirsson.

The specimens collected have been placed in the hands of Mr. Whitman Cross and are to be studied in connection with cognate rocks obtained by myself and others from a great system of dikes occurring in areas to the west and south of the locality under consideration. As the result of a preliminary examination he informs me that they are properly designated syenite-porphyry. The essential constituents are biotite, augite, and alkali feldspars, and as the ferro-magnesian minerals predominate, the rocks are basic. They are porphyritic in structure, and large phenocrysts of biotite are characteristic.

[1] Proc. Colorado Scientific Soc., Vol. III, Part 2, p. 226, 1889.

[2] Bull. Geol. Soc. Am., Vol. VI, pp. 389–422 (1895) ; Am. Jour. Sci., 3d ser., Vol. L, pp. 467–479 (1895); 4th ser., Vol. I, pp. 283–301, 467–479 (1896). The authors refer also to descriptions of European localities.

Fragments of various rocks are included in the laccolites and dikes, and are of interest as revealing the nature of lower-lying terranes through which the ascending liquid passed. Besides sandstones and shales similar to those constituting the wall rocks, the most abundant as well as the most notable rock is a porphyritic granite with conspicuous crystals of gray feldspar.

The age of the laccolitic intrusion is not closely determined. The youngest formation involved in the deformation is the Dakota. The Neocene sand rests undisturbed on the worn edges of the deformed strata. Manifestly the intrusion was subsequent to the one and antecedent to the other. These limits stand wide apart, but a little consideration will show that the epoch of intrusion was probably not close to either. In discussing the laccolites of the Henry Mountains, the writer reached the tentative conclusion that a heavy load of overlying rocks was a condition essential to the formation of a large laccolite, and the body of data which has since been gathered is rather confirmatory of this conclusion than otherwise. If this be admitted we must assign to the intrusion a date at which the Dakota sandstone was covered to a great depth by other formations. It is known from the general history of the region that the deposition of the Dakota was followed by that of the Colorado and Montana groups, and it is possible that these were here succeeded by the Laramie also. Subsequently all these beds were eroded, not only from this particular district but from an extensive tract of the Great Plains province, and much time was necessarily consumed in this work. It seems therefore probable that the date of the igneous intrusion belongs either to the closing epochs of the Cretaceous period or to the earlier half of the Eocene period.

The porphyrites and cognate rocks which elsewhere constitute the greater number of laccolitic masses are notable for their durability. Not only are they so hard as to resist corrasion stubbornly and cause the diversion of such small streams as may chance to flow athwart them when they are discovered by the general degradation of the country, but they yield with

extreme slowness to the ordinary processes of disintegration. It results that in regions of rapid degradation laccolites usually survive all associated rock-masses and find topographic expression in steep-sided mountains or buttes. In these respects the rock of the Twin Butte locality is strongly contrasted. It weathers more easily than the associated sandstone, so that dikes traversing sandstone outcrops are sometimes not easy to trace; and it is scarcely more durable than the associated shales. The dikes do indeed stand prominent above shale areas, but this is occasioned largely by the baking of the shales along the planes of contact, and also in part by an alteration of undetermined character which in some instances affects the dike rock for a few inches from the planes of contact. Where the laccolites are in contact with shales the latter are modified for many feet or yards, being rendered much more durable than the igneous rock. It results that the exposed parts of laccolites, being weaker than all the associated sedimentaries, are characterized topographically by valleys.

I. C. Russell, reasoning from the dominance of acid rocks among laccolites, the frequent occurrence of basic rocks as thin sheets, and the viscosity of acid magmas as compared to basic at the same temperatures, has recently suggested[1] that great viscosity is an essential condition of the production of thick intrusive lenses. As this theory encounters serious difficulty in the new data from Montana and southeastern Colorado, I venture an alternative suggestion involving a different point of view. The topographic features associated with the weak basic rocks at Twin Butte are inconspicuous, whereas those of the resistant porphyrites of the Elk and Henry mountains are bold and striking. Is it not possible that the basic rocks are really well represented in laccolites, but have as yet received little notice because in the gradual development of the subject the more salient features have first caught the eye?

G. K. GILBERT.

[1] JOUR. GEOL., Vol. IV, pp. 179–180, 1896.

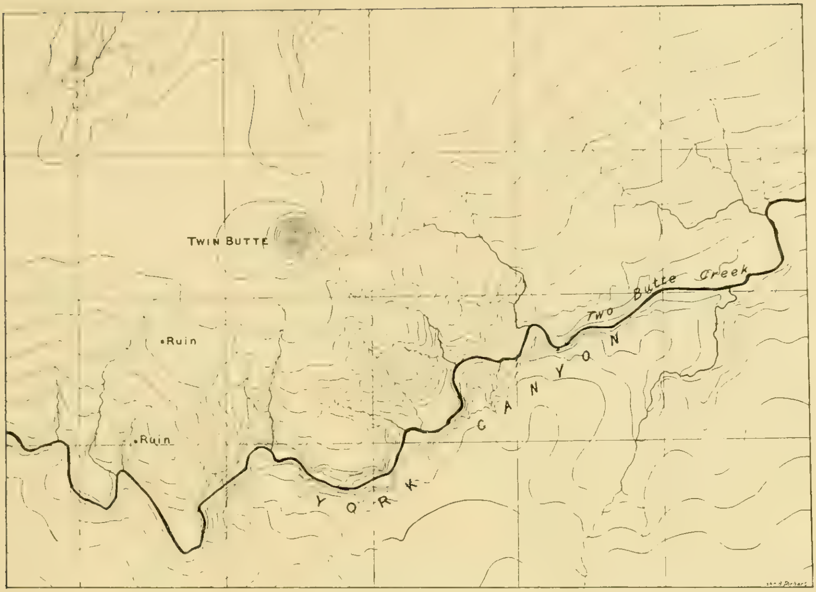

FIG. 1.—Topographic map, contour interval, 25 feet.

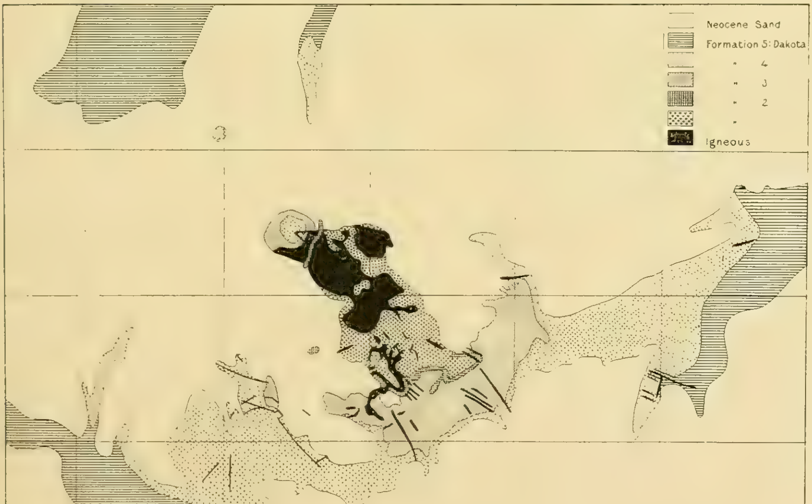

FIG. 2.—Geologic map of same area. Laccolites in southeastern Colorado.

FIG. 3.—Twin Butte and the crest of the arch, from a point on the plain two miles northeast.

FIG. 4.—Ideal cross-section of igneous intrusion.

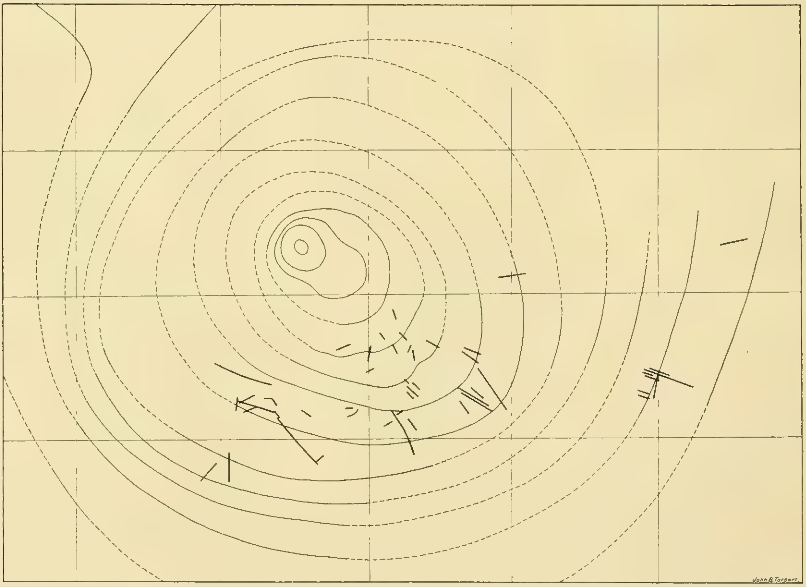

FIG. 5.—Deformation map. See explanation at end of text. Laccolites in southeastern Colorado.

EXPLANATION OF FIGURES.

All of the figures except the landscape view have the same scale. Each of the three maps represents the same area. To aid in their comparison vertical and horizontal lines are drawn at intervals corresponding to one mile.

FIG. 1. Map of Twin Butte and vicinity, showing the topographic relief by contour lines at every 25 feet.

FIG. 2. Geologic map of Twin Butte and vicinity, showing the distribution of the surface formations described in the text.

FIG. 3. Landscape. In the foreground the plain of Neocene alluvium. At the right, Twin Butte. At center and left, the crest of the laccolitic dome, dissected by drainage flowing in the direction from the observer and descending rapidly to Two Butte Creek. The rocks capping these low hills are shales hardened by reaction from the laccolite beneath.

FIG. 4. Ideal cross-section of the igneous intrusion, from east to west. The profile of this is constructed from the contours of deformation (Fig. 5) on the assumption that the intrusives constitute a continuous mass dividing the sedimentaries at a single horizon. It is known that this assumption is not strictly true, but the meager data at command do not suggest an improvement. The diagram shows for each point the total uplift of the cover and therefore the total thickness of intrusive rock.

FIG. 5. Deformation map of Twin Butte and vicinity, showing, by means of contours at intervals of 100 feet, the form which would appear if the eroded parts of formation 3 (Fig. 2) were restored, and all overlying formations were removed. Where the positions of the contours are controlled by the geologic data the lines are full. The broken lines are interpolated. The other lines of the figure mark the position and trend of dikes.

ITALIAN PETROLOGICAL SKETCHES.

II. THE VITERBO REGION.

Bibliography.—The writings of the early Italian geologists, such as Brocchi, Pareto, and Ponzi, are of such small petrological value at the present time that nothing need be said of them here.

The first to describe the region according to more modern methods was vom Rath,[1] who devoted parts of two of his Italian *Fragments* to its description. This is largely topographical, but contains many petrographical details and some analyses, which will be referred to later. Stoppani[2] also, in 1873, gives a brief account of the region.

Through the kindness of Sig. Caposavi I was enabled to obtain a copy of Dr. Barbieri's pamphlet, entitled *I Vulcani Cimini e Vulsinii* (Viterbo, 1877), which is out of print and very rare. It proves to be a popular but graphic sketch of the geological history of this and the Bolsena regions.[3]

In 1880 A. Verri[4] published a somewhat extended description based on personal observations. Accompanying it is a geological map, which is on a small scale, and a much idealized section. His petrographical determinations are not based on microscopical examination of thin sections, and hence leave much to be desired. After the descriptions of the various rocks and remarks on their distribution, he gives a sketch of the Tertiary and post-Tertiary history of the volcano, as he deduces it from his observations.

[1] VOM RATH, Zeit. d. d. Gesell., XVIII, 577–585, 1866; XX, 294–307, 1868.

[2] Corso di Geologia, Milan, 1873, III, 387.

[3] This is mentioned since the work is scarcely known, and the bibliography published in the Boll. Com. Geol. Ital. for 1886 mentions it only by title.

[4] VERRI, Atti Acc. dei Lincei., VIII, 3–34, 1880.

A few analyses of eruptive rocks from this center were published in 1884 by Ricciardi,[1] but, as he expressly states that they are of groundmass carefully freed from phenocrysts, they are unfortunately of comparatively little use to us.

A few years later Bucca[2] published some short petrographical descriptions of various rocks from this locality. He concludes that two distinct types are found in the region, "one essentially trachytic, the other leucitic. These two types often appear isolated and clearly distinct; at other times there has been a mixture of one with the other." He further thinks that the trachyte is younger than the leucitic rocks and argues from this an increase in acidity during successive eruptions.

In 1889 appeared the latest works on this region so far as my knowledge extends. The paper by G. Mercalli[3] is a purely petrographical account of the principal rocks with short but useful descriptions. He distinguishes the two types of trachytic and leucitic rocks, and shows that the latter are later than the former. He also gives numerous mineralogical details of a series of ejected blocks, which are also described elsewhere by E. Artini.[4]

The other paper of this year is that of Deecke,[5] which constitutes one of his series of excellent articles on Italian geology. The first part of the article is devoted to a discussion of some of Verri's views and an exposition of his own regarding certain features of the volcano. The second part describes at length the ejected blocks found in the tuffs of Monte Vico, and the third describes various eruptive rocks collected by himself. An almost complete bibliography precedes the paper. Lacroix[6] also describes many of the ejected blocks and segregations from this region.

The best maps are those issued by the Italian government.

[1] RICCIARDI, Atti Acc. Gioen. Catania, XIX, 1884.

[2] BUCCA, Boll. Com. Geol. Ital., 1888, 57–63.

[3] MERCALLI, Rendic. Institut. Lomb., XXII, 1889.

[4] ARTINI, Atti Acc. dei Lincei, VI, 1889.

[5] DEECKE, Neu. Jahrb., B. Bd. VI, 205–240, 1889.

[6] LACROIX, Les Enclaves des Roches, Macon, 1893.

The southern part of the region is included in the completed Bracciano Sheet (Foglio 143, scale 1:100000) of the Geological Map of Italy.

Topography.—The Viterbo region lies a few kilometers southeast of Lake Bolsena, Viterbo being the chief town and best headquarters. It resembles in many respects the Bolsena region. East of Viterbo and in the northern part of the region lies the group of high hills known as the Monti Cimini, the early bulwark of the Etruscans against the Romans. The largest of these is Monte Cimino, a curving ridge running north and south, convex toward the east, its highest point 1053 meters above the sea and about 800 above the plateau of Viterbo. Connected with this and forming part of the same orographic mass are the lower Monti di Vitorchiano, Soriano, and La Pallanzana.

These, it may be said here, were formed by the older eruptions of the region. They are wholly built up of volcanic materials—lava streams and beds of tuff and a tuff-like rock. Stretching out around Monte Cimino to north, east, and west are lava streams and beds of trachytic tuff.

Immediately to the south of Monte Cimino, and southeast of Viterbo, is the most striking feature of the region—the great crater-ring of Monte Vico. This is almost circular in shape, its symmetry being broken by the projection of Monte Fogliano in the middle of its western side. Its greatest diameter—from north to south—is about five kilometers, and its widest part east and west is nearly as great.

The highest point of its rim is the summit of Monte Fogliano, 963 meters above sea level, the highest point on its northern edge being 896 meters, on the east 696, and on the south 607. It thus resembles the Bolsena, Latera, and other craters of Italy in having its southern rim the lowest. The inner slope is quite steep. Vom Rath estimates the average at 20°, which, judging from my own observations, seems much too low. In places, as on the east, and, according to vom Rath, on the south, it is quite precipitous. When not hidden by forests of oak trees it is seen that the walls are made up of beds of tuff with lava streams

and masses of lava blocks, tuff generally constituting the highest part of the ridge. The lavas of Monte Vico are predominantly leucitic, a few phonolites also having been observed.

The southern part of the interior of the crater is occupied by a lake whose surface is 507 meters above sea level. Its depth does not seem to have been ascertained, but it is apparently shallow. At the southeast corner an emissary has been cut for drainage purposes. Eventually the lake will probably give place to a plain, through drainage of its waters and filling up by denudation of the surrounding easily eroded tuff walls, as is the case at Agnano and elsewhere in Italy.

In the northern part of the crater there rises from the alluvial plain left by contraction of the lake from its original limits the so-called Monte Venere (Venus Mountain). This is a rounded hill with steep sides, whose summit is 317 meters above the lake level. The dense growth with which it is covered makes proper study of it difficult, but as far as I could judge it is a compact unstratified mass of eruptive rocks—a "dome" of leucite-trachyte. Part of the southeast flank is covered with pumiceous scoriæ, but elsewhere all such detrital material is lacking. Stoppani and Ricciardi mention a lava stream as flowing down its western side, which however I did not see, nor is it spoken of by Verri and Deecke.

From the ring wall of Vico the surface slopes gradually down on all sides at a low angle, except to the north where the Monti Cimini break the regularity. This surface is made up of yellow and gray tuffs containing leucitic, pumiceous, and some phonolitic blocks, as well as blocks of metamorphosed limestone, etc., such as are described by Deecke and Mercalli. Deep ravines—so characteristic of the surface topography of these regions—have been cut out by erosion, and diverge radially on all sides. Flank eruptions, which are so common at Bolsena, seem to be almost entirely wanting.

On the outskirts of the volcano the tuff and lava beds rest on late Eocene, and also in places on Pliocene deposits. Immediately to the south of the Vico crater lies the Bracciano region,

with its great crater lake, which will form the subject of the next paper.

It may also be noted that volcanic activity seems not yet entirely extinguished, since several hot springs occur in the neighborhood. The best known of these is that of Bulicame, which lies about 2^{km} to the west of Viterbo. This was probably known to the Romans, is mentioned by Dante, and is still flowing abundantly. The temperature of the water is 80°.[1] Verri also notes a few others near Ronciglione and Orte, and calls attention to the great deposits of travertine as evidence of the former abundance of mineral springs in the region.

We see from the above sketch that the structure of the region is somewhat different from that of the Bolsena region, since we find external to the great crater ring, and older than it, the Monti Cimini, and inside it the younger dome of Monte Venere.

A much more thorough study than has yet been attempted must be devoted to the region before all the problems it presents can be solved, but mention may here be made of the chief theories which have been proposed to account for some of its features. Since Verri's paper is the most detailed that we possess on the region it will not be out of place to quote briefly from his own résumé[2] of his views on the geological history and structure of the volcano.

According to him eruptions of fragmentary material broke out toward the close of the Pliocene period, and resulted in forming an island of trachytic tuff in the midst of the shallow sea. This was followed by eruptions of more solid material which formed Monte Cimino in the center of the island. After retreat of the sea consequent upon upheaval of the surface, which fractured the dome, trachytic lavas were poured out of the fissures thus made.

After this there was opened the Vico vent, both vents erupting simultaneously at first, though the eruptions of Monte Cimino soon ceased. With the opening of the Vico vent there

[1] Daubeny, Volcanos. London, 1848, 160.

[2] Verri, op. cit., 33.

appears a new mineral, leucite, which increases in abundance till toward the close it predominates largely over the other constituents. The eruptions of leucitic lavas were followed by those of lapilli, terminated by an explosion which threw out of the cone torrents of mud, burying the surrounding country for a distance of ten to fourteen kilometers.

The internal equilibrium of the cone was disturbed by the eruption of this vast amount of fragmentary material, and the greater part of the cone sank in, Monte Venere alone remaining above the waters of the lake—a fragment of the former summit which the action of the weather has reduced to a cone-shaped figure.

There are grave objections to be brought against certain points of this sketch, and Deecke devotes considerable space to arguments against two of them. He holds that Monte Cimino was not the result of a "domal" eruption of pasty trachytic magma followed by lava streams, as vom Rath and Verri believe, but that the mountain is part of what remains of the large crater ring of a true strato-volcano. The northwest wall of this has entirely disappeared and of the original cone only Monti Cimino, Valentano, La Pallanzana and one or two others are left. The crater was filled up, partly by its own eruptions and partly by the ejections from the neighboring Vico crater.

He agrees with Verri in thinking that the latest eruptions from the Cimino crater took place after those of Monte Vico had begun; but regards them as composed of "petrisco," which he considers with vom Rath to be a trachyte enclosing many leucites derived from the Vico lavas.

The arguments which he brings up against Verri's views that the crater lake of Vico is due to a sinking in of the top of the cone, and that Monte Venere is a half-sunken fragment, seem to me to be quite conclusive. They are so well given in his easily accessible paper that the reader is referred to it for a full presentation of them. He considers the crater a double one, due to powerful explosions, perhaps aided somewhat by sinking, and Monte Venere a true dome or *puy*—the last eruption of the

volcano. It may also be added that Stoppani combats Verri's views on these two points, as well as on the eruption of torrents of mud.

Though my own opportunities for observation were too limited to permit me to deal authoritatively with these problems, yet it may be of use to state briefly my own views. I am inclined to regard the Cimini eruptions as largely of a domal type, though lava streams and tuffs are more abundant than is usually the case with this type of volcano. Vom Rath's and Deecke's view as to the origin of the leucite phenocrysts in the "petrisco" I cannot agree with — a point which we shall have occasion to examine later on. I most decidedly concur with Deecke and Stoppani in considering the crater lake of Vico due chiefly to explosive eruptions, but think it probably a single crater, and that Monte Venere is a dome, representing the last eruption in the region. It is also well established that here, as at Bolsena, the leucitic lavas were later as a whole than the trachytic.

PETROGRAPHY.

We have to deal here, as in the Bolsena region, with two chief types of rocks, a trachytic and a leucitic. Petrographically the two regions are also alike in other more detailed features. The most important of these is the occurrence of a class of rocks intermediate between the trachytes and the andesites, which form a group of effusive rocks corresponding to some of Brögger's monzonites.

Vulsinite.—Of rocks corresponding to this type of intermediate effusive rocks characterized by the presence of both orthoclase and a basic plagioclase, there came to my notice only two occurrences, both being on the western border of the region. One is from Massa di San Sisto, about 7^{km} southwest of Viterbo on the road to Vetralla, where it forms a flow from the direction of Monte Fogliano cut through by the road. The upper part is visible here and there, though largely covered with travertine and leucitic tuffs. It is somewhat decomposed and fresh speci-

mens were hard to obtain. The other comes from near Vetralla 13^{km} southwest of Viterbo, from a quarry whose exact location I could not ascertain. It may be from the same flow as the one first mentioned since the two closely resemble each other. The second is a light gray, harsh, typically trachytic rock. The groundmass is fine-grained and contains small biotite and augite phenocrysts, with many glassy tabular feldspars. The sp. gr. of this rock is 2.611 at 11°. The first is similar in character, but its color is a light reddish brown due to atmospheric decomposition. The feldspars are larger than in the other, and much resemble the sanidines of the well-known Drachenfels trachyte.

Under the microscope the two present much the same appearance. The phenocrysts are of orthoclase with fewer of labradorite, which contain few inclusions, the labradorite being included in the orthoclase; many well-formed phenocrysts of pale green diopside, including patches of brown glass and some magnetite; and some of brown biotite (especially abundant in the second rock), which is much corroded and "altered," though generally a core of unaltered substance remains.

The groundmass is holocrystalline and typically trachytic. Many small colorless or very pale green diopside prisms and anhedra, with not abundant magnetite grains, lie in a paste of alkali feldspar and fewer plagioclase laths showing flow structure. Between these laths in the second rock there is some alkali feldspar as cement, which is almost entirely wanting in the first. Stout apatite prisms with gray dusty inclusions are very common, and there are also a few small brown biotite flakes.

An analysis of the Vetralla specimen is given in No. 1 of Table II. Comparison will show the great resemblance between it and that of the typical vulsinite from Bolsena.[1] Its mineralogical composition is also almost identical, though labradorite takes the place of anorthite and is somewhat less abundant apparently. It may be said that the rock was thought to be rather a plagioclase-bearing trachyte till the analysis showed its essential identity with vulsinite.

[1] This Journal, IV, 552, 1896.

Very similar, if not identical rocks from the western part of the region are described by vom Rath and Mercalli, and Verri also speaks of them. The "biotite-hypersthene-trachyte" from I Capuccini at Monte La Pallanzana described by Rosenbusch[1] also belongs here. He speaks of labradorite as abundant. A section of this rock which I obtained from Sturtz belongs apparently to the "peperino" described later. Bucca does not mention these rocks but describes a "trachyte" from Casaccia, at the southern end of Lake Vico. In this, however, he mentions olivine as visible megascopically, and a plagioclase as abundant both as phenocrysts and in the groundmass so that it is probably to be referred to the following group of rocks. This is also probably the same rock as that from near Ronciglione which Mercalli briefly describes as an "andesitic olivine-trachyte."

Ciminite.—The main mass of the Monti Cimini is made up of a peculiar rock, which occurs in streams and perhaps also as domal masses. In several places this rests on Pliocene clays, which have been more or less metamorphosed at the contact.[2]

The proper position of this rock in our classification has been uncertain almost from the first. Vom Rath calls it a trachyte, while Deecke refers it to the augite-andesites, though each acknowledges that the name chosen does not quite agree with the characters of the rock. Vom Rath indeed says that were it not for its sanidine content it would fit better into the augite-andesites; while Deecke remarks that it approaches basalt on the one hand through its content of olivine, and trachyte on the other by its structure and large sanidines. Bucca describes the rock from Madonna della Quercia (which, as Deecke says, belongs here) as a trachyte; though he mentions, without commenting on the peculiarity, that the phenocrysts are chiefly of abundant olivine and augite, with few of feldspar. He describes the rock from Fontana di Fiesole as a leucitic trachyte, but speaks vaguely of "distinguishing two parts in the rock, one composed essentially of leucite, the other forming a rock similar

[1] Rosenbusch, Mikr. Phys., II, 771, 1896.

[2] Vom Rath, op. cit., 299.

to those described [trachytes]." We have already seen that his "trachyte" from Casaccia probably belongs here. Mercalli also calls the Cimino rock an olivine-trachyte.

I was unfortunately unable to obtain specimens from the main mass of Monte Cimino, but those which I collected from the flows back of Madonna della Quercia and at Fontana di Fiesole[1] are of essentially the same type of rock. A specimen from below San Rocco in the Vico crater probably belongs to this latter center of eruption.

These rocks are all very compact, one of my specimens from Fontana di Fiesole alone showing a few elongated vesicles. Their color is light gray, that from the Vico crater being slightly greenish. In the fine-grained groundmass are scattered abundant small phenocrysts of pale yellow olivine, with small black augites, and fewer small glassy sanidines, the rock from Madonna della Quercia showing the most of these last. The Fiesole rock has a sp. gr. of 2.70 at 10° C.

Under the microscope they present much the same features, the only marked differences being in the greater or less development of feldspar and pyroxene in the groundmass. Feldspar phenocrysts are very rare in the slides and are seen to be both of orthoclase and plagioclase. No sections of the latter were found by which its exact character could be definitely determined, though it seems to be a rather basic labradorite. The feldspar phenocrysts are much corroded.

There is a great abundance of large and small phenocrysts of olivine, but this does not occur as a true groundmass constituent. They show the normal forms, more or less corroded, and are colorless and perfectly fresh in the interior. All show, however, a narrow, bright reddish-brown border, so frequent on olivine, and apparently of the same substance as that which has received the name of iddingsite.[2] This covers original crystalline, corrosion, and fracture surfaces alike, though here and there a small

[1] DEECKE (op. cit., 240) states that this flow probably belongs to the Bolsena center. He does not give the reasons for this view, and my own observations leave no doubt in my mind that it belongs to Monte Cimino.

[2] A. C. LAWSON, Bull. Dept. Geol., Univ. Cal., I, 31, 1893.

fracture is seen which does not show it. I am inclined to agree with Deecke in the view that some action of the magma is responsible for the existence of this border, since, as in his specimens, the perfect freshness of all the other minerals seems to exclude any appreciable meteorologic decomposition. The olivine is quite free from inclusions, except a few magnetite grains.

Diopside phenocrysts are also abundant, in fact more so than those of olivine. Only the largest show in the section a faint green color, the great majority being quite colorless. They are all well formed and automorphic, showing the usual planes with a stout prismatic habit, but the largest have suffered somewhat in transit and are more or less fractured. The extinction angle on *b* (010) reaches 45°, that of the interior being slightly higher than that of the border. In a few cases olivine crystals were noticed protruding into, and hence older than, the diopside. In the rock from Madonna della Quercia a single large crystal of brown biotite was seen, associated with large crystals of feldspar. It was much corroded, being reduced to a carious condition.

All these lie in a groundmass which shows both andesitic and trachytic features. Except in the rock from Vico crater, where diopside is comparatively rare, there is a typically andesitic "felt" of small diopside needles with many magnetite grains, the interstices being filled with feldspar. This is in the form of laths and also of "cement." The laths are both of orthoclase and of plagioclase in much smaller amount. Carlsbad twins are sometimes seen in the former, but twinning lamellæ are rare in the latter, which is chiefly to be distinguished by its oblique extinction and higher refractive index. Both are surrounded occasionally by narrow mantles of orientated alkali feldspar. The cement is entirely of alkali feldspar. Little or no apatite was noticed. Glass is present in small amount in the rock from Madonna della Quercia, but is almost entirely lacking in the other specimens.

The above description will have made evident the difficulty of classifying these rocks. As has already been said, the scarcity

of orthoclase phenocrysts, the abundance of plagioclase and presence of olivine, with the andesitic structure of the groundmass, would incline one to call them andesites, while the abundance of orthoclase in the groundmass inclines one towards the trachytes. At the same time the olivine is much more abundant than is usually found in an andesite, and the striking feature of the comparative rarity of the feldspars among the phenocrysts gives them a decidedly lamprophyric aspect.

Similar difficulties are met with when we come to examine the analyses of these rocks given below:

TABLE I.

	1	2	3	4
SiO_2	55.44	58.67	56.32	56.76
Al_2O_3	18.60	15.07	18.17	16.79
Fe_2O_3	2.09	——	2.23	2.07
FeO	4.48	8.35	6.47	6.95
MgO	4.75	2.97	2.84	1.63
CaO	6.76	8.07	5.33	6.01
Na_2O	1.79	3.36	1.80	2.43
K_2O	6.63	3.50	4.18	4.67
H_2O	0.25	0.82	2.15	2.44
TiO_2	0.16	——	——	——
P_2O_5	Trace	——	0.34	0.47
Sum.	100.75	100.81	99.83	100.22
Sp. Gr.		2.765	2.520	2.470

1. Fontana Fiesole, Viterbo. H. S. Washington anal.
2. West slope of Monte Cimino. Vom Rath, *op. cit.* 304.
3. Mont' Alfina. Bolsena Region. Ricciardi anal. Klein, *op. cit.* 7.
4. Sassara. Bolsena Region. Ricciardi anal. Klein, *op. cit.* 7.

Here we see that while as regards the silica, alumina, iron and lime they approach the andesites rather than the trachytes, yet that the potash is largely in excess of the soda and that the rock is far richer in total alkalies than is the case with the true andesites. The magnesia also is abnormally high.

We see, then, that this rock can be properly classed neither with the andesites nor the trachytes, but that, like the vulsinite previously described,[1] it occupies a position intermediate between

[1] This JOURNAL, IV, 547, 1896.

the two. Its position is, however, not exactly intermediate, since the large amount of magnesia and the presence of olivine throw it somewhat out of line. For these effusive rocks, characterized mineralogically by the presence of orthoclase with basic plagioclase, augite or diopside, and olivine, and chemically by rather low silica (53–58 per cent.), high magnesia and potash, high alkalis, with more potash than soda, and andesitic amounts of alumina, iron, and lime, I would propose the name of *ciminite*,[1] from their earliest known and most characteristic locality. It may be mentioned here that these rocks, as well as the vulsinites, show many analogies with the absarokite-banakite series from the Yellowstone Park described by Iddings.[2] Their relations with these, as well as with the other trachy-andesitic and the leucitic rocks of Italy will be discussed in the final paper.

"*Peperino.*"—With the above may be described a rock concerning whose true character there has been much conflict of opinion. This is a soft, incoherent rock, easily cut with tools, which is much used for building purposes in the neighborhood. It goes locally by the name of "peperino," and was called by Brocchi "necrolite," on account of its use by the Etruscans for their sarcophagi and for the excavation of their tomb-chambers. It is quarried extensively at Bagnaia, to the east of Viterbo, where it rests on Pliocene beds and forms the oldest known product of the Ciminian eruptions.

This rock is called by vom Rath a trachyte, by Verri a trachytic tuff, by Mercalli a "quartz-bearing andesitic trachyte" or dacite, and by Deecke a mica-andesite. There is thus here, as in so many other instances, a great discrepancy among the various writers in regard to its character. The rock is too abundant, and too well known and much used in the region, and the descriptions tally too well to allow us to entertain the idea that the various observers are dealing with different materials. In this case I must decidedly agree with Verri in calling it a

[1] Pronounced chiminite.

[2] This JOURNAL, III, 935, 1895.

tuff, and consider it as derived from one of the peculiar trachy-andesites which are such a feature of this volcanic district.

I obtained my specimens fresh from the large quarries near Bagnaia, where it forms thick masses traversed by numerous fissures. Evidences of stratification were wanting. It is covered by looser beds of gray tuff containing, as pointed out by Verri and Deecke, many fragments of pumice and blocks of ciminite or a similar rock.

When first quarried it is very soft and friable, but hardens a great deal on exposure. It is rather coarse grained, made up of grains of feldspar, biotite, and augite, embedded in a finely granular paste. I could find none of the quartz mentioned by Mercalli. Its general color is a light yellowish gray, with spots and streaks of dark brown and gray, which give it somewhat the appearance of the well-known "piperno" of Pianura, near Naples.

Under the microscope it is seen to be composed of fragments of clear orthoclase, somewhat less abundant basic plagioclase (near labradorite) showing many twinning lamellæ, many brown and somewhat decomposed biotite crystals often frayed at the edges, and less numerous grayish green augites, all lying in a dusty, dirty, ill-defined groundmass. The fragmentary character of all the crystals is most marked, and there is lacking to all the constituents that definiteness of form and arrangement which characterizes true effusive rocks. The appearance is almost identical with that of many undoubted tuffs — so much so as to leave no doubt in my mind that the Bagnaia occurrences, at least, must be regarded as fragmental, and not effusive.

The only doubt cast upon this view is the presence in one slide of a large patch of obsidian. This shows similar, but much less broken, feldspar, biotite, and augite crystals, lying in a highly vitreous groundmass, which is made up of a clear, colorless isotropic base, flow structure being well brought out by abundant, damascene-like streaks of fine gray dust. These streaks curve about the large crystals, and also follow the line

of junction of the obsidian with the rest of the section. The contact line is rather vague, and close to the obsidian there are seen in the dusty groundmass some indications of a similar and parallel flow structure.

This patch might then be evidence in favor of the rock being a much decomposed and devitrified, highly vitreous, andesitic mica-trachyte, were it not for the wholly fragmentary condition of the crystals and the general similarity of the rock with other tuffs. The indications of flow structure seen in the dusty groundmass might be explained by the idea that they are due to the presence of part of the thin flake of obsidian extending beneath the tuff proper in the section. Such a flow structure is, however, clearly visible in such undoubted tuffs as those of Monte Epomeo on Ischia, and Monte Barbaro in the Phlegræan Fields and the obsidian-like patch may be due to secondary silicification. I may add that the view that the rock is a tuff accords better with the lack of contact metamorphism in the underlying Pliocene beds as commented on by Verri[1] and Deecke.[2]

Leucitic rocks.—These rocks, as we have seen, are confined apparently to the Vico center, though according to vom Rath and Deecke the latest ejections of the Cimino volcano were leucite-bearing.

There seems to be much less variety among the leucitic rocks of this region than was found among those of the Bolsena region. All the specimens which I collected may be referred to leucite-trachyte, and the same seems to be the case with those described by others, with a few exceptions to be noted presently.

Leucite-trachyte.[3]—This rock, which is known locally by the name of "*petrisco*," is very abundant in the region, forming flows and blocks in tuff around Monte Vico, as well as the domal Monte Venere. The flow occurrences are generally fresh, com-

[1] VERRI, op. cit., p. 26. [2] DEECKE, op. cit., p. 228.

[3] In Zirkel's sense, leucite phonolite of Rosenbusch. *Cf.* this JOURNAL, IV, 555, 1896.

pact, and extremely tough, while those forming ejected blocks in the tuff are so decomposed as to be very friable.

The flow specimens show a number of flat vesicles whose walls are smooth and occasionally coated with small crystals of nepheline, as was noticed by vom Rath. The groundmass is dark gray and very compact and aphanitic.

Through this are scattered leucite crystals in profusion, which make up in places over a third of the bulk of the rock and seldom fall below one-quarter, giving the rock a most characteristic appearance. The crystals are of good size, generally 0.5 to 1.0^{cm} in diameter, usually perfectly formed with sharp edges, but occasionally in fragments. While sometimes fresh and of the usual gray color and waxy luster (in one case yellowish through infiltration of ferruginous water), they are usually dull white, due to alteration. In the most altered specimens this kaolinization reduces them to a very friable and mealy condition. They include grains of augite and magnetite, which are irregularly arranged or clustered at the center. Apart from the leucites few phenocrysts are present, there being some sanidines and a few black augites.

In thin section the leucite-trachyte of Madonna di Lauro[1] near Vetralla, and that from a stream in the crater wall of Vico below San Rocco, which are typical of my Vico leucite rocks, present much the same characters. The large leucites are much cracked and exert little action on polarized light, the characteristic twinning being seen only in a few places. This is probably due to incipient or, as in the Vico rock, to evident alteration. There are not very abundant inclusions of augite, feldspar, magnetite, and glass. In the yellow leucites of one rock deposits of limonite are noted along all the crevices, while the leucite substance itself is quite colorless.

Feldspar phenocrysts are not uncommon, those of alkali feldspar being largely in the majority over those of plagioclase, which is a basic labradorite. Light brown glass inclusions are common, generally clustered toward the center. The pyroxene

[1] This is described by BUCCA, op. cit., 61.

phenocrysts are of a very pale green diopside and are highly automorphic. Some show evidences of fracture and corrosion, while a few have at the ends a late fringing growth of small diopside needles arranged parallel to the vertical axis. Except for a few large magnetite grains other phenocrysts are wanting.

The groundmass is decidedly andesitic in structure. Small stout needles of diopside, and of the brown pleochroic barkevikite-like hornblende seen in Bolsena leucite-tephrites,[1] many small alkali feldspars and a few plagioclase laths, and many well-shaped magnetites lie in a colorless glass base with absolutely no evidence of flow structure. Here and there are small round spots of a colorless substance whose inclusions and analogies with similar forms in others of these Italian rocks show them to be leucite, though their double refraction is scarcely visible. Apatite needles are also present in all the specimens. The colorless base is isotropic and seems to be entirely of glass. No nepheline could be detected with certainty. In one rock some alkali feldspar flakes are also present, and the glass in many places is of a light brown color.

Analyses of two of these rocks are given in Table II, Nos. 4 and 5. They resemble each other fairly well though 5 is lower in SiO_2 and Al_2O_3 and higher in iron oxides and lime. The analysis of the groundmass of a leucite-trachyte from the Vico Crater, by Ricciardi (No. 6), shows somewhat lower silica, extremely high alumina, considerably more lime, and less iron and alkalis. These are what we would expect to find, except the very high alumina, and perhaps the lower iron.

A few specimens of much decomposed petrisco from blocks in the latest tuff also deserve mention. They are so friable as to crumble readily between the fingers, rendering it difficult to obtain good specimens. The groundmass is black or brownish-black and very fine grained. This is thickly peppered with small and large leucites, with a few small sanidines, which stand out prominently against the dark background. The leucites in general are perfect and well formed, though some fragments

[1] Cf. this JOURNAL, IV, 562, 1896.

occur. They are all of a dull pure white and extremely friable —due to a process of kaolinization. A few small augite phenocrysts are also visible.

Under the microscope they resemble somewhat those just described, the differences being largely due to decomposition. The large leucites, many of which have fallen out, are of a pale yellow color and quite isotropic. The original leucite substance has given place to a peculiar alteration product which here and there is subfibrous in structure, but more often resembles a gum. It is filled with perlitic cracks which split it up into spheroidal masses.

The groundmass is very fine-grained and rather hyalopilitic in structure, formed of a felt of small diopside and alkali feldspar laths with magnetite grains, lying in a base either of brownish glass or glass with flakes of orthoclase. Scattered through it are small leucites, from 0.02 to 0.07^{mm}, which, though perfectly isotropic, leave absolutely no doubt as to their real nature, since they show the characteristic isolated inclusions, and often the still more characteristic skeleton forms previously described.

The leucites in these rocks, as well as in some of the flows, are supposed by vom Rath, Bucca, and Deecke to be inclosures derived from leucitic lavas of Monte Vico which were caught up during the eruption of Ciminian "trachytes." This view is based on the supposed facts that the leucite is always phenocrystic, is always or generally in fragments, is always kaolinized, and also on the chemical composition of the rock.

With this theory I cannot agree. In the first place my own observations lead me to agree with Verri (p. 29) in thinking that the greater part, if not all, of this petrisco-bearing tuff was derived from the Vico crater. Furthermore, the leucite, while chiefly present as phenocrysts, also occurs abundantly in the groundmass as we have seen. The fragmentary character of the large leucites did not appear to me to be nearly as universal as stated by the above writers; and even were it so it would not be surprising when the peculiar molecular condition of the mineral is

considered.[1] In all the occurrences which I saw and in all my hand-specimens the perfection of form of the tetragonal trisoctahedron is very striking, and furthermore the abundance of the leucites is too great to countenance the idea of their accidental presence. The state of alteration does not seem to me to have any bearing on the case, since this is dependent on surface conditions and would go on the same no matter what the origin of the crystals. The argument may rest on the ground that a trachytic magma would be at a higher temperature than a leucitic magma, but this idea is not expressed by either of the above writers. Vom Rath's analysis of petrisco is given in Table II (No. 6), and while it differs considerably from those of similar rocks from the Bolsena and other regions in containing less lime and magnesia and more silica and alkalis, yet it can be closely paralleled by analyses of similar rocks containing undoubtedly primary leucites to be described later.

The rock composing the dome of Monte Venere, which forms the last eruption of the region, is also a leucite-trachyte, but of a somewhat different type. The groundmass is very compact with only a few small vesicles, and the color is light gray. It is very tough under the hammer—a characteristic of most of the leucite rocks of all these regions. The leucite phenocrysts are neither as numerous nor do they stand out as prominently as in the preceding types, being small, quite fresh and glassy, and of a pale grayish white color. There is an abundance of very small phenocrysts of dark pyroxene and some small scales of biotite. The sp. gr. of this rock is 2.609 at 10° C.

Under the microscope leucite is seen to be a much more generally distributed constituent than in the preceding, or than the megascopical examination would lead us to suppose. It runs down from the larger phenocrysts to very small crystals of the groundmass, of which it forms a very large part. It seldom shows definite crystal boundaries; and inclusions, as well as double refraction, are rare.

Feldspar phenocrysts are common, and plagioclase is more

[1] Cf. ROSENBUSCH: Mikr. Phys., I, 311, 1892, and II, 826, 1896.

abundant than in the preceding rocks, which led Mercalli to call it a leucite-tephrite. They all carry very narrow irregular mantles of orientated alkali feldspar. The pyroxene is quite similar to those already described, but the green color is deeper and the augite molecule evidently surpasses that of the diopside. It frequently carries inclusions of apatite needles.

The most prominent difference in these Monte Venere rocks is the presence of quite numerous phenocrysts of brown biotite, which show strong pleochroism. They are quite fresh over the greater part of their area, but carry borders of large and loosely coherent augite and magnetite grains. A few are entirely altered and only represented by clusters of these grains showing roughly the original form. The groundmass is largely made up of small round leucite anhedra. Between these lie many laths and flakes of alkali feldspar, fewer augite microlites, and many magnetite grains, all of which are imbedded in a colorless glass base with no apparent flow structure. There is no evidence of the presence of nepheline. An analysis of this rock is given in Table II, No. 7.

The above descriptions embrace all the leucitic rocks collected by myself, but a few of a different character are described by other observers. Deecke mentions leucite-basanite as occurring on the south shore of Lake Vico, as well as among the lapilli of Monte Venere; and Mercalli notes a similar rock from San Martino, between Viterbo and Monte Fogliano. Bucca also describes an olivine-bearing leucite-tephrite from Capo d'Acqua, near Vetralla. Mercalli speaks of leucite-tephrites as occurring in several places, but his brief descriptions leave it uncertain whether leucite-trachytes are not intended. He also mentions a leucitic-phonolite as occurring in erratic blocks in the tuff which carries the phonolites described later. Deecke describes a number of leucite-phonolites (leucitophyrs) from Piazza, on the southeast shore of Lake Vico, from below San Rocco, and from Borghetto near Civita Castellana, east of the volcano. This last probably belongs to a flank eruption. They closely resemble the leucite-trachyte first described, except that they carry

nepheline in the groundmass. The apparently total absence of leucitites, which is commented on by Mercalli, is a most striking fact, and in great contrast to the adjacent centers of Bolsena and Bracciano.

Phonolites.—The presence of these rocks would seem to be an exception to the statement on a previous page that the Viterbo rocks can be divided into only two classes. They occupy, in fact, an exceptional position, occurring only as blocks in the last tuff ejected by Monte Vico and in a couple of dikes observed by Deecke. Their total amount is moreover very small, quite subordinate to those of the ciminites and leucite-trachytes. Of these rocks I collected three specimens. One is from a loose block in the yellow tuff west of Viterbo, another from a block in the tuff at the Posta on the north edge of the Vico crater. They are very compact and tough, with no great tendency to break into slabs under the hammer. In the aphanitic, greenish gray, slightly greasy groundmass are a few small glassy sanidine phenocrysts, stained light brown in places, still fewer small dark pyroxenes, and here and there a bright blue speck of haüyne. The sp. gr. is 2.509 at 10°.

Under the microscope it presents a normal phonolitic structure of Rosenbusch's nephelinitoid type. The large orthoclase phenocrysts are clear and free from inclusions, though a little brown limonitic material lies along the cracks. They are tabular parallel to the clinopinacoid, show commonly Carlsbad twinning, and often have corroded outlines. Mantles of orientated alkali feldspar are common. The rather rare augite phenocrysts are well formed and of an olive green color, and quite strongly pleochroic. Since the axis of greatest elasticity $\mathfrak{a}$ makes an angle of about 30° with the vertical axis they belong to the ægirine-augites.

Rather large haüynes are quite abundant and frequently show octahedral and cubic planes. They are generally colorless in the interior and bright blue toward the edge, though sometimes blue all over, or brown inside and blue out. They show the peculiar inclusions arranged in fine parallel straight lines, often

forming systems at right angles. These are best developed at the borders of the crystal. Haüyne is occasionally seen included in, and hence older than, large orthoclase phenocrysts.

The groundmass is holocrystalline and composed of small ægirine prisms and alkali feldspar laths scattered through a paste of nepheline, which occasionally shows characteristic crystal boundaries. The powdered rock gelatinizes abundantly with acids, the solution furnishing cubes of sodium chloride, and staining of the slides renders the identity of the nepheline certain. There are also present some small magnetite grains, quite abundant apatite needles, and a number of bright colorless highly refracting grains and crystals of titanite, which often show the characteristic pyramidal forms and rhombic sections. No leucite was seen.

An analysis of this rock by the writer is given in Table II, No. 9, the alkali percentages being the means of $Na_2O=4.86$ and 4.90, and $K_2O = 9.21$ and 9.06, so that their relative amounts are beyond question. The analysis by vom Rath of his "phonolitic trachyte" is shown by No. 10. It would seem possible that there has been a transposition of the figures for the alkalis in vom Rath's paper.[1] This phonolite is then noteworthy for its very high potash content, which explains the large amount of orthoclase seen in thin sections. The amount of lime being very small and having been exhausted in the formation of diopside, and the potash having taken up most of the silica to form orthoclase the soda left from the ægirine went chiefly into nepheline rather than into albite.

Mercalli describes the above rocks under the name of "haüynitic sanidinite," but does not mention nepheline, though he says that they have the megascopic characters of phonolite. The description of the rock which vom Rath (p. 580) calls a phonolite-like trachyte from the Ciminian Mountains answers in every way to those just described, except that it is said by him to contain leucite and that it is quarried. The exact locality is not

[1] The discrepancy between the analysis and the description of the rock is commented on by ZIRKEL (Lehrbuch, II, 467).

given. He does not mention nepheline but speaks of a mineral in the groundmass which "may be sanidine," and states that the rock gelatinizes abundantly with HCl. The analysis (No. 9, Table II) is hardly that of a leucite-phonolite, so that the rock may be classed as a phonolite with accessory leucite.

A phonolite of a somewhat different character is from a lava stream in the steep inner wall of Monte Vico, north of Monte Venere. This is a compact fine-grained gray rock, highly vesicular in structure, with a few small nepheline crystals visible on the walls of the vesicles. Glassy twinned tabular sanidines are abundant. Under the microscope it is seen to belong rather to the trachytoid type of Rosenbusch. The orthoclase phenocrysts are similar to those of the preceding specimens, but the rare pyroxene phenocrysts are rather augite proper than ægirine-augite. No haüyne is to be seen, but shreds of much altered brown biotite are found here and there. The groundmass is quite trachytic in character, the ægirine needles being less abundant and alkali feldspar laths much more so than in the other type, with marked flow structure. These, with considerable magnetite and some very small titanite grains, lie in a holocrystalline paste of what is apparently a mixture of orthoclase and nepheline. The former is in somewhat large flakes, and the latter distinguishable by its very weak double refraction and its behavior with acids.

Deecke describes some true phonolites which form two dikes in the eastern crater wall of Monte Vico. They correspond very closely to those described above. It is worthy of note that phonolite also occurs as a dike at Le Braidi on the eastern flank of Monte Vulture,[1] but has not been observed among the other products of this volcano.

Analyses.—In Table II are given the most reliable of the few analyses of the rocks of this region. No. 5 was made for me by Dr. A. Röhrig of Leipzig. No. 2 was made in the Mineralogical-Petrographical Laboratory of Yale University under the direction of Professor L. V. Pirsson, to whom I take the opportunity

[1] DEECKE, New Jahrb., B. Bd. VII, 602, 1891.

of returning my sincere thanks for his invaluable aid and advice. Nos. 7 and 9 were made in my own laboratory. The discussion of these analyses will be reserved for the final paper.

TABLE II.

	1	2	3	4	5	6	7	8	9	10
SiO_2	57.32	55.44	58.67	59.51	55.26	54.41	55.21	55.08	59.24	60.18
Al_2O_3	19.85	18.60	15.07	18.89	16.36	22.91	19.81	18.31	18.97	18.70
Fe_2O_3	2.21	2.09	....	....	5.26	1.45	2.69	1.67	3.30	....
FeO	2.35	4.48	8.35	5.26	2.90	4.67	2.86	7.06	1.20	3.44
MgO......	1.60	4.75	2.97	1.50	1.14	1.54	1.68	2.18	0.12	0.32
CaO......	3.82	6.76	8.07	1.90	3.90	6.73	4.61	5.79	2.06	2.80
Na_2O	3.22	1.79	3.36	4.99	4.08	[1] 1.64	3.13	[1] 1.34	4.87	9.67
K_2O	9.15	6.63	3.50	7.25	8.82	5.36	8.45	6.59	9.14	4.18
H_2O	0.57	0.25	0.82	0.56	1.20	1.53	0.99	2.19	0.86	0.33
TiO_2	....	0.16	....	....	0.36	....	Trace	....	0.48	....
P_2O_5	....	Trace	....	....	....	Trace	....	Trace	....	....
Cl........	....		....	0.19	....	....	....	....	....	0.14
SO_3	....	....	....	....	....	....	....	....	0.10	0.19
	100.09	100.75	100.81	100.05	99.28	100.24	99.43	100.21	100.34	99.95
Sp. Gr.....	2.611	2.700	2.765	2.603	.....	.....	2.609	.....	2.509	2.522

1. Vulsinite, near Vetralla, H. S. Washington anal.
2. Ciminite, Fontana Fiesole, Viterbo, H. S. Washington anal.
3. Ciminite, West Slope of Monte Cimino, vom Rath, *op. cit.*, 304.
4. Leucite-Trachyte, "Petrisco," Viterbo, vom Rath, *op. cit.*, 298.
5. Leucite-Trachyte, Madonna di Lauro, Vetralla, A. Röhrig anal.
6. Leucite-Trachyte, *Groundmass*, Vico Crater, Ricciardi, *op. cit.*
7. Leucite-Trachyte, Monte Venere, H. S. Washington anal.
8. Leucite-Trachyte, *Groundmass*, Monte Venere, Ricciardi, *op. cit.*
9. Phonolite, block in Tuff, west of Viterbo, H. S. Washington anal.
10. Phonolite, Monti Cimini, vom Rath, *op. cit.*, 581.

HENRY S. WASHINGTON

[1] Trace of Li_2O.

STUDIES FOR STUDENTS.

THE PRINCIPLES OF ROCK WEATHERING.

(*Concluded.*)

(*c*) MECHANICAL ACTION OF WATER AND OF ICE.

ASIDE from its solvent capacity, water acts as a powerful erosive agent, as well as an agent for the transportation of the eroded materials. It is only its erosive power that need concern us here, though as we shall see this is to a considerable extent dependent upon its power of transportation. Every raindrop beating down upon a surface already sorely tried by heat and frost serves to detach the partially loosened granules, and, catching them up in the temporary rivulets, carries them to the more permanent rills to be spread out over the valley bottoms, or perhaps if the slopes be steep and the current accordingly strong to the rivers and thence to the sea. The amount of detrital matter thus mechanically removed from the hills and spread out over valley and sea bottoms quite exceeds our comprehension, but it is estimated that at the rate the Mississippi River is now doing its work the entire American continent might be reduced to sea level within a period of four and one half million years. The Appalachian Mountain system has already, through this cause, lost more material than the entire mass of that which now remains. But the rivers, like the winds and glaciers, in virtue of this load of sand they bear, become themselves converted into agents of erosion, filing away upon their rocky beds, undermining their banks and continually wearing away the land by their ceaseless activity. The pot-holes in the bed of a stream, formed by the constant swirl of sand and gravel in an eddy, furnish on a small scale striking illustrations of this cutting power, while the rocky canyons of the Colorado of the west, where thousands of feet of horizontal strata have been cut through as with a file,

show the same thing on a scale so gigantic as to be at first scarce comprehensible.[1] An item of no insignificant importance to be considered here, is the possibility, indeed probability, of an incidental chemical decomposition taking place during this abrasive action.

Daubree has shown[2] that when feldspathic fragments were submitted to artificial trituration in a revolving cylinder containing water, a decomposition was effected whereby the alkalies were liberated in very appreciable amounts. He found further that the principle product of mutual attrition of feldspathic fragments was an impalpable mud (limon) of such tenuity as to remain for many days in suspension, and which on desiccation became so hard as to be broken only with the aid of a hammer, resembling in many respects the argillites of the Coal Measures, but differing in that it carried a high percentage of alkalies. Granitic rocks thus treated yielded angular fragments of quartz and very minute shreds of mica, while the feldspars ultimately quite disappeared in the form of the impalpable mud above mentioned. It was noted that after a certain degree of fineness had been reached further rounding of the particles ceased, owing to the buoyant action of the water, which, in the form of a thin film between adjacent particles, acted as a cushion and prevented actual contact to the extent necessary for mutual abrasion. It is to a similar action on the part of sea water that Shaler[3] would attribute the lasting qualities of the sand grains upon our sea beaches. Indeed the conditions of Daubree's experiments as a whole were not so different from those existing in nature that we need hesitate to conclude that similar action, both chemical and physical, may be going on wherever abrasion takes place in the presence of continual moisture, as in the bed of a river or glacier.

The hammering action of the waves upon the seacoast exert

[1] CAPTAIN C. E. DUTTON has estimated (Tertiary History of the Grand Canyon of Colorado) that from over an area of 13,000 to 15,000 square miles drained by the Colorado River an average thickness of 10,000 feet of strata have been removed.

[2] Geologie Experimentale, p. 268.

[3] Bull. Geol. Soc. of America, Vol. V, p. 208.

a powerful erosive action, particularly upon particles of rock of such size as to be lifted or moved by wave action, but too heavy to be protected from attrition by the thin film of water above alluded to. Shaler's observation[1] at Cape Ann were to the effect that ordinary granitic paving blocks (weighing perhaps twenty pounds) were, when exposed to surf action worn in the course of a year into spheroidal forms such as to indicate an average loss of more than an inch from their peripheries. Experiments made with fragments of hard-burned brick showed that in the course of a year they would be reduced fully one-half their bulk. Even the crystallization of the salt thrown up by wave action and absorbed into the pores of rocks[2] serves in its way the purposes of disintegration.

The action of freezing water and of ice.—The action of dry heat and cold in disintegrating rocks has already been described. The effects of such temperature changes upon stone of ordinary dryness are however slight in comparison with the destructive agencies of freezing temperatures upon stones saturated with moisture. The expansive force of water passing from the liquid to the solid state has been graphically described as equal to the weight of a column of ice a mile high (about 150 tons to the square foot). Otherwise expressed, one hundred volumes of water expand, on freezing, to form one hundred and nine volumes of ice. Provided then sufficient water be contained within the pores of a stone, it is easy to understand that the results of freezing must be disastrous. That stones as they lie in the ground do contain moisture, often in no inconsiderable amounts, is a fact well-known and well-recognized by all those engaged in quarrying operations, and indeed no mineral substance is absolutely impervious to it. The amount contained naturally varies with the nature of the mineral constituents and their state of aggregation. According to various authorities granite may con-

[1] Bull. Geol. Soc. of America, Vol. V, p. 208.

[2] According to DANA (Wilkes Exploring Expedition. Geology, p. 529) the sandstones along the coast of Sydney, Australia, are subjected to a mechanical disintegration through the crystallization of the salt which is absorbed from the saline spray of the ocean waves.

tain some 0.37 per cent. by weight; chalk, 20 per cent.; ordinary compact limestone, 0.5 per cent. to 5 per cent.; marble, about 0.30 per cent., and sandstones varying amounts up to 10 or 12 per cent., while clay may contain nearly one-fourth its weight. At and near the surface the amount, particularly after rains, may be very considerably increased. This water is largely interstitial —the *quarry water*, as it is sometimes called. In addition to this the quartz, particularly of granitic rocks, almost universally contains innumerable minute cavities partially filled with water, and which are in extreme cases so abundant as to make up, according to Sorby, at least 5 per cent. of the whole volume of the mineral.

That the passage of this included moisture from the liquid to the solid state may be attended with results disastrous to the stone is self-evident, though the rate of disintegration may be so slow under favorable circumstances as to be scarce noticeable. Freezing of the absorbed water is one of the most fruitful sources of disintegration in stones confined in the walls of a building, and even in the quarry bed it is by no means uncommon to have the material so injured as to render it worthless. However slight may be the effects of a single freezing upon a rock, constant repetition of the process cannot fail to open up new rifts, and still further widen those already in existence, allowing further penetration of water, which freezes in its turn, and exerts a chemical action as well. So year in and year out, through winter's cold and summer's heat, the work goes on until the massive rock becomes loose sand to be caught up by winds or temporary rivulets and spread broadcast over the land. In some instances, it may be, the rock is of sufficiently uniform texture to be affected in all its mass alike. More commonly, however, it is traversed by numerous veins, joints or other lines of weakness along which the rifting power is first made manifest. Naturally disintegration of this kind is confined to frigid and temperate latitudes. As bearing upon the extreme rapidity with which such disintegration may take place, I quote the following from a letter of Dr. L. Stejneger, of the Smithsonian Institution, who passed several months among the islands of Bering Sea:

"In September, 1882, I visited Tolstoi Mys, a precipitous cliff near the southeastern extremity of Bering Island. At the foot of it I found large masses of rock and stone which had evidently fallen down during the year. Most of them were considerably more than six feet in diameter, and showed no trace of disintegration. The following spring, April 1883, when I revisited the place I found that the rocks had split up into innumerable fragments, cube-shaped, sharp-edged, and of a very uniform size, about two inches. They had not yet fallen to pieces, the rocks still retaining their original shape. I may remark, however, that the weather was still freezing when I was there. The winter was not one of great severity and several thawing spells broke its continuity. These cubic fragments did not seem to split up any further, for everywhere on the islands where the rock consisted of the coarse sandstone, as in this place, the talus consisted of these sharp-edged stones."

Ice acts as an agent of disintegration in still other ways than that mentioned above. Glaciers and their attendant phenomena have, however, been so thoroughly discussed of late in the columns of this and allied journals that my remarks upon the subject may here be very brief. The moving glacier transports more or less rock débris fallen upon it from the hills on either hand or picked from the surfaces over which it flows. Those materials which are carried upon the surface, or frozen in the upper portions of its mass, may be but transported to the lower levels, where, the temperature being sufficient, the ice is melted and deposits its load in the form of a moraine. Those which become frozen into the ice-sheet at its under surface are crowded, as the glacier moves onward with all the weight of the overlying mass and all the resistless energy of the ice behind, over the surface of the underlying rocks. In virtue of this material, this sand, gravel and bowlder aggregate, the glaciers become converted into what we may compare to extremely coarse files, to tear away the rocks over which they pass and grind and crush them into detritus of varying degrees of fineness. The small streams which originate from the melting of these glaciers become, hence, not

infrequently charged to the point of turbidity with the fine silt-like detritus ground from the ledges and in part from the bowlders themselves. This feature has been so frequently noted in geological text-books, as to need no farther mention here.

(*d*) *Action of plants and animals.*—Both plants and animals aid to some extent in the work of rock degeneration.

The lowest forms of plant life, the lichens and mosses growing upon the hard, bare face of rocky ledges, send their minute rootlets downward into every crack and crevice, seeking not merely foothold but food as well.

Slight as is the action it aids in disintegration. The plants die, and others grow upon their ruins. There accumulates thus, it may be with extreme slowness, a thin film of humus, which serves not merely to retain the moisture of rains but also to bring the rock under the influence of chemical action. As time goes on, sufficient soil gathers for other, larger and higher types of life, which exert still more potent influences. It may be the rock is in a jointed condition. Into these joints each herb, shrub, or sapling pushes down its roots, which in simple virtue of their gain in bulk, day by day, serve to enlarge the rifts and furnish thereby more ready access for water, and the wash of rains to still further augment disintegration. This phase of root action is often well shown in walls of ancient masonry, either of brick or stone, where they greatly accelerate the usual rate of destruction. The depth to which such roots may penetrate has often been noted,[1] varying, as is to be expected with the nature of the soil. In the limestone caverns of the southern states the writer has often noted the number of long thread-like rootlets which have found their way through rifts in the rocky roof, so fine as to be almost imperceptible. In this, as in others of nature's processes, we must remember that nothing is done in haste. With boundless time, and resources without limit, Dame Nature works out her results at her own time and by her own methods.

[1] Aughey has found roots of the buffalo berry (*Sheperdia argophylla*) penetrating the loess soils of Nebraska to the depth of fifty feet.

Aside from this physical action plants promote disintegration by keeping the surface of rocks continually moist, and through their decay by supplying the complex series of compounds commonly called humic, ulmic, crenic and apocrenic acids to which reference has already been made. These act both as deoxidizing and solution agents.

"There is reason to believe that in the decomposition effected by meteoric waters and usually attributed mainly to carbonic acid, the initial stages of attack are due to the powerful solvent capacities of the humus acids. Owing, however, to the facility with which these acids pass into higher states of oxidation, it is chiefly as carbonates that the results of their action are carried down into deeper parts of the crust or brought up to the surface. Although CO_2 is no doubt the final condition into which these unstable organic acids pass, yet during their existence they attack not merely alkalies and alkaline earth, but even dissolve silica." [1]

It is stated by Storer that "on the tops of the higher hills of New Hampshire, and on the coast of Maine also, a cold, sour black earth will often he noticed at the surface of the ground, immediately beneath which is sometimes a layer of remarkably white earth. The whiteness is due to the solvent action of acids that soak out from the black humus, and which leach out from the underlying clay and sand the oxides of iron that formerly colored them, leaving only the insoluble pure clay or sand."

H. Carrington Bolton has shown that very many minerals are decomposed by the action of cold citric acid for a more or less prolonged period, the zeolites and other hydrous silicates being especially susceptible. Such tests have a peculiar significance when we consider that the roots of growing plants secrete an acid sap

[1] GEIKIE, Text-book of Geology, 3d ed., p. 472. The writer was shown not long since, a very practical illustration of the remarkable corrosive power of organic acids. A highly ornate French clock with case of black marble was packed for storage in excelsior which was a trifle damp. The clock remained in storage from the last of May until about the first of October. When the packing material was removed, the marble was found to be so corroded as to need rehoning and polishing. The roughness could be easily felt by passing the finger over the surface, and long lusterless lines indicating the contact of excelsior fibers traversed the surface in every direction.

which by actual experiment has been found capable of etching marble. The exact nature of this acid is not accurately known, but it is considered probable that in the rootlets of each species of plant there exist a considerable variety of organic acids.[1]

But the effects of plant growth are not necessarily always destructive; they may exert a conservative or even protective action. In glaciated regions it is often the case that the striated and polished surfaces of the rocks have been preserved only where protected from the disintegrating action of the sun and atmosphere by a thin layer of turf or moss. As a general rule, however, the manifest action of plant growth is to accelerate chemical decomposition, through keeping the surfaces continually moist, and to retard erosion.

Action of bacteria.—The researches of A. Müntz,[2] Widogradsky, Schlösing and others have shown that bacteria may exercise a very important influence in promoting rock disintegration and decomposition. Their influence in promoting nitrification has been already alluded to. It would appear that while these organisms may secrete and utilize for their sustenance the carbon from the carbonic acid of the atmosphere, as do plants of a higher order, they may also assimilate the carbonate of ammonium, forming from it organic matter and setting free nitric acid. Being of microscopic proportions these organisms penetrate into every little cleft or crevice produced by atmospheric agencies, and throughout long periods of time produce results of no inconsiderable geological significance. The depth below the surface at which such may thrive is presumably but slight, and their period of activity limited to the summer months. They have been found on rocks of widely different character—granites, gneisses, schists, limestones, sandstones and volcanic rocks—and on high mountain peaks as well as on lower levels. The Pic Pourri, or Rotten Peak, in the Lower Pyrenees of southwest-

[1] See Application of Organic Acids to the Examination of Minerals. H. CARRINGTON BOLTON, Proc. Am. Assoc. for the Advancement of Science XXXI, 1883. Also Available Mineral Plant Food in Soils. B. DYER, Jour. Chem. Society, March 1894.

[2] COMPTES RENDUS DE L., Academie des Sciences, CX, 1890, p. 1370.

ern France is composed of friable and superficially decomposed calcareous schists throughout the whole mass of which are found the nitrifying bacteria which are believed to have been instrumental in promoting its characteristic decompositions. The organism acts even upon the most minute fragments, reducing them continually to smaller and smaller sizes. Each fragment loosened from the parent mass is found coated with a film of organic matter thus produced, and the accumulation begun by these apparently insignificant forces is added to by residues of plants of a higher order which come in as soon as food and foothold are provided.

Mr. J. E. Mills,[1] as already noted, lays considerable stress on the decomposing effects of the carbonic acid gas which the ants are "continually pouring" into the upper layers of decomposed material. What the original source of this carbonic acid may have been is not stated, but the natural assumption is that it arises from the decomposing organic matter in their burrows.

Certain species of ants, locally known as saubas, or sauvas, live, according to Branner,[2] in enormous colonies, burrowing in the earth where they excavate chambers with galleries that radiate and anastomose in every direction, and into which they carry great quantities of leaves. Certain species of termites, the *white ants* of Brazil, are also active promoters in bringing about changes in the structure of the soil, and incidentally accelerating decomposition. The organic matter carried by these creatures into the ground, there to decompose, furnishes organic acids to promote further decay in the material close at hand, and by its downward percolation to attack the still firm rocks at greater depths. Indeed these numerous channels, through affording easy access of air, and surface waters with all their absorbed gases or alkaline salts, may serve indirectly a geological purpose scarcely inferior to that of the joints in massive rocks.

The mechanical agency which has already been referred to as instrumental in bringing about a certain amount of decom-

[1] Am. Geologist, June 1889, p. 351.

[2] Bull. Geol. Soc. of Am., Vol. VII, 1895.

position in silicate minerals, is greatly augmented when such trituration takes place in connection with organic matter. J. Y. Buchanan has shown[1] that the mud of sea bottoms is being continually passed and repassed through the alimentary canals of marine animals, and that in so doing the mineral matter not merely undergoes a slight amount of comminution and consequent decomposition, but a chemical reduction takes place whereby existing sulphates are converted into sulphides. Such sulphides and the metallic constituents of the silicates and other compounds, particularly those of iron and manganese, would on exposure to sea water become converted into oxides. It is through such agencies that he would account for the presence of sulphur in marine muds, and the variations in color, from shades of red or brown to blue and gray, in the former the iron occurring as oxides, while in the latter it exists as a sulphide. Of course either form may be more or less permanent according as the mud may be devoid of animal life, or protected from oxidizing influences.

3. ANALYSES OF FRESH AND DECOMPOSED ROCKS.

Let us now take into consideration a few common rock types which have undergone a process of degeneration through weathering, and by means of analyses ascertain, so far as possible, the chemical and physical changes which have taken place. In the table below are given, in each case, the results of analyses of fresh and decomposed materials, and the calculated percentage loss of constituents, both as relates to the entire rock, and to the individual constituents. In making these calculations it has been necessary to assume that one of the constituents remains practically constant, in order that it may serve as a basis of comparison. That constituent which has been shown by a large series of analyses to be most constant is, among siliceous crystalline rocks, the alumina, though sometimes it is the iron. Among calcareous rocks it is the silica. In any case,

[1] On the Occurrence of Sulphur in Marine Muds. Proc. Royal Soc. of Edinburgh, 1890–1.

by selecting as a standard of comparison that of the constituents which has suffered the least through the leaching action of water during the process of degeneration, we may gain by calculations which it is unnecessary to repeat here a series of numbers showing the loss of constituents as given below, and which may safely be accepted as rather under than above the actual figures.

ANALYSES OF FRESH AND DECOMPOSED GNEISS.

Constituents	1 Fresh gneiss	2 Decomposed gneiss	3 Loss	4 Percentage amount of each constituent saved	5 Percentage amount of each constituent lost
Silica............. (SiO_2)	60.69	45.31	31.90	47.55	52.45
Alumina .... (Al_2O_3)	16.89	26.55	0.00	100.00	0.00
Iron sesquioxide.. (Fe_2O_3)	9.06	12.18	1.30	85.65	14.35
Lime .... (CaO)	4.44	trace	4.44	0.00	100.00
Magnesia .... (MgO)	1.06	0.40	0.80	25.30	74.70
Potash .... (K_2O)	4.25	1.10	3.55	16.48	83.52
Soda .... (Na_2O)	2.82	0.22	2.68	4.97	95.03
Phosphoric acid ... (P_2O_5)	0.25	0.47	0.00	100.00	0.00
Ignition .... (H_2O and C)	0.62	13.75	0.00	100.00	0.00
Total loss			44.67		

ANALYSES OF FRESH ELÆOLITE SYENITE AND RESIDUAL KAOLIN.

Constituents	1 Fresh syenite	2 Residual kaolin	3 Loss	4 Percentage amount of each constituent saved	5 Percentage amount of each constituent lost
Silica .... (SiO_2)	59.96	45.81	37.28	37.82	62.18
Alumina .... (Al_2O_3)	18.92	38.19	0.00	100.00	0.00
Ferric Iron ...... (Fe_2O_3)	4.87	1.34	4.19	13.83	86.17
Lime .... (CaO)	1.35	0.33	1.19	12.10	87.90
Magnesia .... (MgO)	0.69	0.25	0.57	17.90	82,10
Potash .... (K_2O)	6.00	0.23	5.90	18.15	81.85
Soda .... (Na_2O)	6.32	0.37	6.15	2.89	97.11
Ignition........... (H_2O)	1.84	13.48	0.00	100.00	0.00
Total loss...........			55.28		

ANALYSES OF FRESH AND DECOMPOSED DIORITE.

Constituents	1 Fresh diorite	2 Decomposed diorite	3 Loss	4 Percentage amount of each constituent saved	5 Percentage amount of each constituent lost
Silica .... (SiO_2)	46.74	42.45	17.43	62.69	37.31
Alumina......... (Al_2O_3)	17.61	25.51	0.00	100.00	0.00
Iron sesquioxide..(Fe_2O_3)	16.79	19.20	3.53	78.97	21.03
Lime .... (CaO)	9.46	0.37	9.20	2.70	97.30
Magnesia......... (MgO)	5.12	0.21	4.97	2.83	97.17
Potash............ (K_2O)	0.55	0.49	0.21	61.25	38.75
Soda............. (Na_2O)	2.56	0.56	2.17	15.13	84.87
Phosphoric acid ...(P_2O_5)	0.25	0.29	0.05	80.11	19.89
Ignition .....(C and H_2O)	0.92	10.92	0.00[1]	100.00	0.00
Total loss...........			37.56		

[1] A gain.

ANALYSES OF FRESH LIMESTONE AND ITS RESIDUAL CLAY.

Constituents	1 Fresh limestone	2 Residual clay	3 Loss	4 Percentage amount of each constituent saved	5 Percentage amount of each constituent lost
Silica .... (SiO_2)	4.13	33.69	0.00	100.00	0.00
Alumina .... (Al_2O_3)	4.19	30.30	0.35	88.65	11.35
Ferric oxide ..... (Fe_2O_3)	2.35	1.99	2.13	10.44	89.56
Manganous oxide ..(MnO)	4.33	14.98	2.49	42.41	57.59
Lime .... (CaO)	44.79	3.91	44.31	1.07	98.93
Magnesia .... (MgO)	0.30	0.26	0.26	10.62	89.38
Potash .... (K_2O)	0.35	0.96	0.23	33.63	66.37
Soda .... (Na_2O)	0.16	0.61	0.085	46.74	53.26
Water .... (H_2O)	2.26	10.76	0.95	58.37	41.63
Carbonic acid ......(Co_2)	34.10	0.00	34.10	0.00	100.00
Phosphoric acid ...(P_2O_5)	3.04	2.54	2.73	10.24	89.76
Total loss			77.635		

In reference to these analyses, it is advisable to make the following statement:

The Virginia gneiss, in the first table, in its fresh condition, as analyzed, is a coarse, gray feldspar, a rich variety, with abundant folia of black mica.

Under the microscope it shows the presence of both potash

and soda-lime feldspars, a sprinkling of apatite and iron ores, sporadic occurrences of an undetermined zeolite, and an extraordinary number of minute zircons, which are mostly included in the feldspars. The residual soil resulting from its decomposition is highly plastic, of a deep red-brown color and has a distinct gritty feeling owing to the presence of quartz and undecomposed silicates. Some 69 per cent. of this soil was found to be soluble in dilute hydrochloric and sodium carbonate solutions. It will be noted that 44.67 per cent. of the original matter has disappeared, and that of the original silica 52.45 per cent. is lost, while 85.65 per cent. of the iron and all the alumina and phosphoric acid remain. All the lime has disappeared; 83.52 per cent. of the potash, 95.03 per cent. of the soda and 74.70 per cent. of the magnesia are likewise missing. The total amount of water has increased very greatly, as was to be expected. The calculation shows a small apparent gain in phosphoric acid, but the amount of this constituent is so slight in the original rock as to render it probable that this is due to errors of analysis.

The elæolite syenite in the second series is a coarsely crystalline granular rock containing orthoclase feldspar in broadly tabular forms, accompanied by nepheline, biotite, pyroxene, titanite and apatite, while fluorite, analcite, and thomsonite, together with calcite, occur as secondary products. The rock weathers away to a coarse gray gravel which ultimately yields a clay from which may be obtained, by washing, a kaolin of a fair degree of purity. The analyses are from the work of J. Francis Williams.[1]

The calculations show a much greater loss of silica than in the gneiss, a feature due, as will be noted later, to the absence of free quartz in the syenitic rock. Attention should be called to the fact that the soda has been carried away in greater proportions than the potash.

The diorite in the third series of analyses is, when fresh, a compact fine-grained, almost coal-black rock, sometimes finely speckled with white from the presence of feldspars. The micro-

[1] Ann. Rep. State Geol. Survey of Arkansas, 1890, Volume II.

scope shows it to be composed mainly of hornblende and soda-lime feldspars with interstitial areas of titanic iron. The clay or soil to which it gives rise on decomposing is deep brownish-red in color and highly plastic, though distinctly gritty from the presence of undecomposed feldspars. Though so rich in iron it is to be noted that the residual clay is little if any deeper in color than that from the gneiss. The analysis shows that 37.56 per cent. of the total rock has disappeared.

The limestone of the fourth series is of Carboniferous Age, very impure, crystalline granular, and of a dark chocolate-brown color. The residual clay from its decomposition is a trifle darker, highly plastic and quite impervious. The analyses, calculations, and descriptions are from the work of Penrose.[1]

It is to be noted that all that the lime which existed as carbonate, has been entirely removed, as shown by the absence of carbonic its acid in the clay. Farther, that the clay, notwithstanding highly hydrated condition, in reality contains scarcely half the amount of water it would, had the small amount (2.26 per cent.) in the fresh limestone been allowed to accumulate without loss.

DISCUSSION OF RESULTS AND RÉSUMÉ.

Taking now into consideration in connection with these analyses the statements embodied in the first part of this paper relative to the agencies of degeneration, and making due allowance for possible errors in our methods of calculation, there are certain general deductions that may, apparently, be drawn with safety. In the résumé given below, however, reliance is placed not more upon our own analyses than upon results obtained by others as given in existing literature.[2]

Let us briefly review the subject and make the deductions accordingly.

In glancing over the columns of our analyses it is at once

[1] Ann. Rep. Geol., Survey of Arkansas, 1890, Volume I.

[2] See especially Roth's Allegemeine u. Chemische Geologie, Vol. III, and Ebelman's papers in Annales des Mines, Vols. VII, 1845, and XII, 1847.

apparent that hydration is an important factor, the amount of water increasing rapidly, as decomposition advances. There is, moreover, among the siliceous crystalline rocks in every case a loss in silica, a greater proportional loss in lime, magnesia, and the alkalies, and a proportional increase in the amounts of alumina and sometimes of iron oxides, though the apparent gain may in some cases be due to the change in condition from ferrous to ferric oxide. As a whole, however, there is a distinct loss of materials, though the residuary product may actually contain a larger percentage of certain constituents than did the rock from which it was derived.

According to Bischof and as shown in our own work the silicates in any rock that are most readily decomposed are, as a rule, those containing protoxides of iron and manganese, or lime, and the first indication of decomposition is signaled by a ferruginous discoloration and the appearance of calcite.

Fournet, from a study of the processes of kaolinization, was led to state[1] that the hornblende yields less readily to decomposing forces than does feldspar, when the two are associated in the same rock. Becker, however, in studying deep-seated decomposition in the Comstock lode of Nevada, arrived at a precisely opposite conclusion, the feldspars as a whole offering more resistance than the augite, hornblende, or mica.

The present writer has described[2] thick sheets of augite porphyrite in Gallatin county, Montana, in which the feldspathic disintegration has gone on so far that the mass falls away to a coarse sand, from which still perfectly outlined crystals of coal-black augites may be gleaned in profusion. This last is, however, in a semi-arid region, and the process thus far more one of disintegration than decomposition.

In any climate, minerals consisting chiefly of silicates of alumina and magnesia are less liable to decomposition than those containing iron protoxides, or lime carbonates, for the reason that the first named are not easily affected by carbonic acid.

[1] Ann. de Chimie et de Physique, Vol. LV, 1833, p. 240.

[2] Bull. U. S. Geol. Survey, No. 110, 1894.

Indeed it is ordinarily assumed that the silicate of alumina is not at all affected, but the researches of Müller, to which we have referred, seem to disprove this, as do also the calculations made in previous pages. Those silicates which are least liable to atmospheric decomposition are, as it is to be expected, those which have resulted from the alteration of less stable silicates, as serpentine from olivine, epidote from hornblende, or kaolin from feldspar, etc. So much is this so that serpentine has been called a final product of alteration. A few silicates like tourmaline and zircon, or garnet, or oxides like rutile and magnetite, or the salts of rarer earths like monazite, etc., are scarcely at all affected by any of the ordinary products of decomposition, but remain in the form of residual sands in the beds of streams, from whence the lighter, more decomposed, material is removed by erosion.

In the weathering of potash feldspar rocks carrying black mica, the latter mineral is, as a rule, the first to give way, and at times almost wholly disappears. With basic rocks, on the other hand, the dark mica is one of the most enduring of the constituents, and in the residual sands may be found in surprisingly large proportions.

Among the feldspars the potash varieties are, as a rule, far more refractory than the soda lime, or plagioclase, varieties. This is shown not merely by our own investigations, but by those of others as well. Roth shows[1] from analyses of fresh and weathered phonolites, nepheline basalts, and dolorites that the loss of soda is almost invariably greater than that of potash.

Indeed as shown in our analyses the potash feldspars may lose very little by decomposition, but be converted into the condition of fine silt merely through a mechanical splitting up. This fact will in part explain the relative scarcity of free potassium salts (carbonates, sulphates, and nitrates) as compared with those of soda.[2]

[1] Op. cit., 3d ed., 2d Heft.

[2] An oligoclase occurring in a tourmaline granite on the southern slope of Mt. Mulatto, near Predazzo, undergoes, according to Lemberg (Zeit. der deutsch. geol. Gesellschaft, 28, 1876), a much more rapid decomposition than the orthoclase with which it is associated, and gives rise to a green lusterless serpentine-like product. The

The chemical processes involved in this feldspathic decomposition are of sufficient importance to warrant further discussion, even though it may involve a certain amount of repetition of what has gone before.

Berthier, Forschammer, Brogniart,[1] Fournet,[2] and others explained more than fifty years ago the process of feldspathic disintegration through the breaking up of its complex molecule into alkaline silicates soluble in water and aluminous silicates which are insoluble. The loss in silica, as noted above, was supposed to be due to the removal, by solution, of these alkaline silicates. Ebelman,[3] however, subsequently showed that silicate minerals poor or quite lacking in alkalies lost a portion of their silica with equal facility. He accounted for this on the supposition that the silica set free—in a nascent state—was soluble either in pure water, or water containing carbonic acid. Bischof states that when meteoric waters containing carbonic acid filter through rocks containing alkaline silicates, the first action consists in the partial decomposition of these substances by the carbonic acid, and the formation of alkaline carbonates, which are dissolved.

If the water thus impregnated, on penetrating further below the surface, comes in contact with calcareous silicates, another change will take place consisting of a decomposition and replacement of these calcareous silicates by the alkaline silicates, and a

chemical changes incidental to the alteration are as shown in the following tables, I being the fresh oligoclase and II the decomposition product.

	I.	II.
Silica,	59.51	45.29
Alumina,	25.10	25.68
Iron sesquioxide,	1.08	12.29
Lime,	4.03	0.52
Magnesia,	trace	2.98
Potash,	2.10	3.00
Soda,	7.26	2.14
Water,	0.92	12.49

[1] Arch du Museum, Vol. I, 1839 (cited by Ebelman).

[2] Annales de Chimieet de Physique, Vol LV, 1833.

[3] Annales des Mines, Vol. VII, 1845.

removal of the lime set free, as a carbonate, provided the water still contains a sufficient amount of carbonic acid. This replacing process and the retention of the alkaline silicates is accounted for on the supposition that, in their nascent state, they form new combinations with the other silicates present, while the lime remains as a carbonate to be removed or not as the case may be. He further states that the alkaline carbonates originating in the manner described are among the most soluble substances known; the carbonate of soda requiring for solution only six times its weight of water at ordinary temperatures. Silica, on the other hand, even in its most soluble form, requires 10,000 times its weight of water for solution. If, therefore, the decomposition of feldspar by such carbonated water were ever so energetic, there would be sufficient water for the solution of the carbonate of soda formed. But if the silica separated meanwhile amounted to more than $\frac{1}{10000}$ of the water present, the excess could not be dissolved, but would remain mixed with the kaolin.

The case is very different when the decomposition of feldspar is effected by fresh water containing only minute quantities of carbonic acid. By the action of such water, only very small quantities of alkaline carbonates are formed; consequently it is possible that the silica separated at the same time, also small in quantity, may find enough water for solution. In such cases the whole of this silica would be removed with the alkaline carbonates, and pure kaolin would be left. Such an action as this does not appear to take place; for the purest of kaolin nearly always contains an admixture of quartz sand or of free silica in some of its forms.

H. P. Murakozy[1] has shown that in the decomposition of rhyolite from Nagy-Mihely, the sanidin passes into kaolin and opal, the latter separating out as hyalite in veins or impure concretionary forms. Through this abstraction of silica there is an apparent proportional increase in the amounts of alumina and alkalies.

It follows from the above considerations that in the decomposition of feldspar into kaolin, more of the silica separated remains

[1] Abstract of F. Becke, Neues Jahrbuch, 1894, 1 Band, 2 Heft, p. 291.

mixed with the kaolin formed, the greater the quantity of carbonic acid in water, and that, perhaps, the amount of carbonic acid in water is never so small that the whole of the silica separated in the decomposition of feldspar can be removed.[1] The above, however, wholly overlooks the possible presence of nitrates, such as we now know from the researches noted on p. 857 must in many cases exist even though in extremely small proportions. It is probable that the small amounts of nitric acid formed by the bacteria would, if not at once taken up by plants, combine immediately with the alkalies, potash, or soda, forming nitrates which, owing to their ready solubility, would be carried away. The larger the proportion of nitric acid, therefore, the greater would be the amount of carbonic left, and consequently the greater would be the amount of silica intermingled with the kaolin, since whatever proportion of the alkalies failed to be carried away as nitrates would pretty certainly disappear as a carbonate. There is also the possibility, especially in the rocks rich in iron protoxides, that a portion of the silica may combine with the iron. (See Bischof, Vol. II, p. 77.)

In cases where the decomposition takes place under the influence of a sufficient supply of oxygen, all iron and presumably the manganese as well would be converted into the insoluble hydrous sesquioxide form and remain with the residue. Where, however, the supply of oxygen is insufficient, a portion or all of these constituents may be removed in the form of protoxide carbonates, or, in the case of iron, as a sulphate.

Reference has already been made to the fact that the magnesia from the decomposition of magnesian silicates was sometimes removed in greater relative portions than was the lime. This seeming anomaly is also sometimes met with in calcareous stratified rocks.

Roth[2] states that in the weathering of dolomitic limestones the magnesia is often removed in greater proportional quantities than the more soluble lime carbonate.

[1] Chemical and Physical Geology, Gustav Bischof, Vol II, pp. 182, 183.

[2] Op. cit., Vol. III.

The researches of Hitterman[1] show, however, that carbonic acid solutions *may* exert a scarcely appreciable effect upon magnesian carbonates, which therefore accumulate in the residual soils. In residues derived from limestones this authority also found percentages of alkalies greatly in excess of those in the unchanged rock, indicating beyond a doubt the occurrence of these constituents in the form of insoluble silicates.

It is safe to say that while the general process of rock-weathering may be quite simple, as outlined, there are many minor reactions which it is not possible to describe in detail. It has been shown that even in firm rocks a mutual chemical reaction is not uncommon among minerals lying in close juxtaposition, giving rise to what are known as reaction rims or zones composed of secondary minerals. This is a particularly conspicuous feature in many gabbros where olivine and feldspar are closely adjacent. In these cases a mutual interchange of elements may take place, giving rise to garnets, free quartz or other minerals, as the case may be. This is, to be sure, a deep-seated change, to be classed as alteration rather than decomposition, and taking place presumably under conditions of temperature and solution quite at variance with those existing on the immediate surface. It is, nevertheless, self-evident that when elements are set free through any process, they must almost immediately recombine, taking those forms which existing circumstances may dictate. In a mass of decomposing rock circumstances are almost continually changing, and the inference is fair that new combinations are continually being made and unmade, the intricacies of which we are unable to follow.

Among the siliceous crystalline rocks superficial disintegration is undoubtedly greatly aided by temperature variations which, by rendering the rocks porous, facilitate chemical decomposition. Such action must, however, be merely superficial, and at considerable depths below the surface the change must be purely chemical. The chief conditions favoring chemical action

[1] Die verwitterunge Producte von Gesteinen der Triasformation Franker. Inaug. Dissertation. Munich, 1889.

are those of continual percolation by waters carrying the organic acids already described. It naturally follows therefore that a purely chemical decay will progress more rapidly where the rock-mass is covered by such a layer of vegetable soil as shall give rise to the decomposing solutions. Hence, that such an accumulation having begun decomposition will keep on at an ever increasing rate to a depth concerning which we have at present no data for calculation. It must not be too hastily assumed from this that rocks thus protected do in reality disintegrate more rapidly than those exposed on bare hillsides, since here, where physical causes predominate, the loosened particles are removed as fast as formed, and, besides leaving no measure of the destruction going steadily on, new surfaces for attack are being continually exposed. Moreover, in assuming that rocks decay rapidly where covered by vegetation we must not overlook the fact that the character of the overlying soil may be such as to be protective rather than otherwise. Thus, in glaciated regions it is a well-known fact that the striæ on rock surfaces are found best preserved where they have been protected from heat and frost by a mantle of drift, or the compact turf so characteristic of the northern states.

The principles involved in the decomposition of fragmental and stratified rocks are not so different from those we have been discussing as to call for detailed consideration. It is well to note, however, that the materials composing rocks of this type are themselves a product of these very disintegrating and decomposing agencies, but which have become consolidated into rock-masses, and now, once more in the infinite cycle of change, are undergoing a breaking up. It follows from the very nature of the case that such rocks, with the exception of the purely calcareous varieties, will undergo less chemical change than do those we have been discussing. Their feldspathic and easily decomposable silicate constituents long ago yielded to the decomposing processes, and were largely or in part removed before consolidation took place. Thus most sandstones are composed largely of quartzose sand, the least soluble and least changeable product, it

may be, of many a previous disintegration. Hence, the processes involved in the disintegration of the sandstones, shales and argillites are mainly mechanical, with the exception of those which carry a feldspathic or calcareous cement.

It is, however, quite different with the calcareous members of the group, where, with the exception of the granular-crystalline varieties, the process is almost wholly chemical, and notable for its simplicity. In these latter forms, as the saccharoidal marbles, expansion and contraction, from ordinary temperature variations, bring about a more or less rapid disintegration. The decomposition is, however, due mainly to the action of meteoric waters trickling over the surface, or filtering through cracks and crevices under ordinary conditions of atmospheric pressure and atmospheric temperature. Hence, the process is one of superficial solution, and the incidental chemical processes set in motion, as in the feldspar-bearing rocks, are almost entirely lacking. It follows that only the lime carbonate is removed in appreciable quantities, while the less soluble impurities are left to accumulate in the form of ferruginous clays, admixed with quartzose particles, chert nodules, etc. Since in many limestones the amount of these constituents is reduced to a minimum, even, perhaps, to the fraction of 1 per cent., so it happens that hundreds or even thousands of feet of strata may be removed without leaving more than a very thin coating of soil in its place.

GEORGE P. MERRILL.

EDITORIAL.

IN the American chapter of the third edition of Dr. Geikie's *Great Ice Age*, formational names were proposed for three of the better known till sheets of the glacial series. It was not without some hesitation that this was done because it was not wholly clear that the time was ripe for nomenclature, but the helpfulness of specific names and the superiority of stratigraphic terms over the time-phrases, period, epoch and episode, of controverted application, seemed to overbalance the infelicities that would arise from the immature state of investigation. It was anticipated that further study would give occasion for additions and emendations. The ready and general acceptance of the names seems to have justified their proposal; indeed, other workers in the glacial field have felt that the method might, even at once, be extended to other divisions less well elaborated. To the names Kansan, Iowan and Wisconsin, which were suggested for the three best known till sheets (Toronto being applied to an interglacial fossiliferous deposit, and Aftonian being subsequently added) Dr. George M. Dawson has proposed to add the term Albertan to designate a series older than the Kansan, and Mr. Upham has proposed the addition of Warren, Iroquois and St. Lawrence to designate later till sheets. Previous to these additions Dr. Geikie had proposed a full series of similar names for the European glacial deposits.

The studies of the past two years seem to show that within the limits of the series covered by the three names first proposed, there is, probably, need for some extension and revision. This arises chiefly from the progress made by the geologists of the Iowa Survey, Messrs. Calvin, Bain, Norton and Beyer, and by my colleague, Mr. Leverett. It will be recalled that in eastern Iowa

the elaborate investigations of Mr. McGee some years ago demonstrated the existence of two sheets of till, separated by a vegetal horizon. It was known that in southern Iowa there were also two sheets of till separated by a vegetal horizon, but these had not been studied in detail nor their connections traced out. It was natural, as well as prudentially conservative, to suppose that these two series were mutual equivalents, as they stood in much the same geographic relationship to the later (Wisconsin) drift. It was recognized that the amount of erosion upon the south Iowan series was greater than that upon the east Iowan, and also that the loess in eastern Iowa was intimately connected with the upper till sheet, while the upper till sheet in southern Iowa was separated from the loess by a definite interval, but the importance of these differences was not fully appreciated. The investigations of the Iowa geologists have led to the quite firm conviction that the upper till sheet of the series in southern Iowa is the lower member in eastern Iowa. They have also become convinced that the upper sheet in southern Iowa extends continuously across northwestern Missouri into Kansas, and is the equivalent of the drift sheet that covers the northeastern part of Kansas. State Geologist Keyes of Missouri concurs in this view. They do not hold this to the exclusion of a possible lower member in Kansas. In harmony with these views the upper till in the southern part of Iowa has been designated Kansan in the recent Iowa reports.

During the past summer I have had the pleasure of making two excursions with Mr. Bain of the Iowa survey to localities where the above formations are advantageously exhibited, and I have been impressed with the cogency of the arguments of the Iowa geologists. While, therefore, the case cannot be said to be demonstrative, as yet, it seems best to accept the application of the nomenclature adopted by the Iowa survey. This places the Aftonian beds below the Kansan series instead of above them. It puts the sub-Aftonian sheet of till in an earlier category, and, for the present, it may perhaps be regarded tentatively as Albertan, although, of course, it cannot now be

demonstrated to be equivalent to the Albertan beds of Canada. The studies of Mr. Leverett have made it quite sure that the Kansan ice-sheet crossed the Mississippi and invaded Illinois to some moderate distance. He has also shown that the Illinois ice-sheet returned the compliment and invaded Iowa. Between these invasions there was a considerable interval of time, as indicated by the greater erosion of the Kansan deposits and by the prevalence of a soil horizon and of peat beds between the Kansan and Illinois till sheets where they overlap. He has shown also that there was a notable interval between the invasion of Iowa by the Illinois ice-sheet and the spreading of the loess over its deposits, as indicated by erosion and the formation of a soil horizon. This loess mantle seems to be identical with that which is intimately connected with the east Iowan drift sheet. It thus appears that the invasion of the Illinois ice marks a distinguishable stage of glaciation separated by a notable interval from both the earlier Kansan stage and the later Iowan stage. This interval appears to be of such moment as to make it inadvisable to correlate the Illinois drift sheet with the Iowan drift sheet. As a result, the practice of designating the former the Illinois sheet has already sprung up among us. The evidence at present seems sufficient to justify its tentative use in the literature of the subject. It should of course be credited to Mr. Leverett.

The series in the Mississippi basin, as thus modified, would be as follows in stratigraphic order:

9. Wisconsin Till Sheets (earlier and later).
    8. Interglacial deposits (Toronto perhaps).
7. Iowan Till Sheet.
    6. Interglacial deposit.
5. Illinois Till Sheet (Leverett).
    4. Interglacial deposit (Buchanan of Calvin).
3. Kansan Till Sheet.
    2. Aftonian beds, Interglacial.
1. Albertan Drift Sheet (Dawson).

The completion of the nomenclature by the naming of the interglacial deposits is desirable, but it is doubtful whether it can be satisfactorily done at present. The correlation of the Toronto beds with the Mississippi series seems to me to remain uncertain, but they are so preëminently fitted to give name to their horizon that it seems best to reserve for them the place to which they most probably belong. Some of the known vegetal deposits found below the Iowan till sheet could appropriately give name to the interglacial deposits between the Iowa and Illinois beds if their horizon could be positively fixed, but it cannot now be stated certainly whether the interval marked by these is that between the Iowan and Illinois sheets, or that between the Illinois and Kansan sheets. The Buchanan gravels are regarded by Professor Calvin as marking the initial stages of the interval following the formation of the Kansan drift, and the term Buchanan has been employed by him in designating this interval. The probable close connection between the formation of these gravels and the underlying drift renders the name something less than ideal as the designation of true interglacial deposition, but the pronounced characteristics of the formation and its great significance, joined to its excellent exposure and easy accessibility, make it doubtless the best nominative deposit now available.

While returning from my last visit to the field in which the Kansan, Illinoian, Iowan, and Wisconsin formations were seen in close succession, I made a memorandum of impressions respecting their relative ages simply as a means of comparison with judgments formed at other times, the impressions being derived from the respective degrees of erosion and chemical change which the formations have undergone. Although this was intended to be nothing more than a record of passing impressions, it may be the best means of giving some notion of my rating of the historical importance of the formations. Taking the interval from the late Wisconsin deposits (as found immediately south of the Great Lakes) to the present date as unity, the following is the memorandum:

From the close of the later Wisconsin to the present, - -	1 unit
From the earliest Wisconsin (Shelbyville moraine) to the present, - - - - - - - - -	2½ units
From the Iowan to the present, - - - - - - -	5 "
From the Illinois invasion of Iowa to the present, - - -	8 "
From the Kansan to the present, - - - - - -	15 "
From the sub-Aftonian (Albertan) to the present, - - -	x "

Four of the investigators previously named who have seen this memorandum are disposed to increase the figure for the Kansan, and some of them would alter other figures in the same direction, with perhaps a reduction of the estimate for the Iowan. After the estimate had been made it was observed that the intervals form a symmetrical diminishing series. The temperature variations of the period might therefore be represented by an oscillating curve with declining waves.

T. C. C.

Reviews and Abstracts.

Physical Features of Missouri. By Curtis Fletcher Marbut. *Geological Survey of Missouri*, Vol. X, pp. 1–109, 1896.

This report represents one of the first attempts on the part of a state geological survey to interpret the physical geography of the state concerned from the modern standpoint. The report brings out many interesting facts and relations, even though the topographic map of the state is not complete, and all the data which the area may ultimately afford for the interpretation of its geography are therefore not now available.

The general physical features of the state are discussed from the standpoint of history. The processes of their evolution, and their dependence on geological structure are emphasized, thus bringing out what geographers have long recognized—that any rational interpretation of geography must be based upon a knowledge of geological structure.

The general physiographic provinces of the state are outlined, and their leading characteristics succinctly set forth, and set forth in such a way as to give them a meaning. It is not too much to say that any one who masters this part of Mr. Marbut's report will have a conception of many of the common processes by which topography is developed, and will have acquired some ability to interpret geography for himself.

In the discussion of the hydrography of the state, the same fundamental principles of treatment are followed. Various types of drainage, as drainage is now classified, are found to exist within the state, and specific illustrations are pointed out. It is one of the evidences of the right methods of river study now in vogue, that they are found to fit regions which had not been studied when they were adopted. Many special features of valleys as developed in Missouri are discussed, and new illustrations of various well-known principles are furnished. River meanders come in for special and discriminating discussion.

One of the chief objects to be attained by the systematic treatment of physical geography by the state surveys is educational. It is in every way desirable to disseminate accurate information among the people, and to have the information in such form that it will stimulate independent study. Another object is to furnish professional geographers with accurate knowledge of the region studied. Mr. Marbut's report must be looked upon as more successful from the standpoint of geographers, than from the standpoint of those who are not. Judged from the standpoint of the reader who is not posted in the principles and nomenclature of modern geography, the report is in danger of seeming unnecessarily technical and so of not being understood. This danger is enhanced by the fact that it occasionally lacks in clearness, both because the language is obscure, and because of the lack, at some points, of adequate illustration. Another defect in the same line appears in the frequent references to places which no accompanying map locates. From the standpoint of the geographer these defects may not be serious, but from the standpoint of the citizen who is not a geographer, it is to be feared that they will too often cause the report to remain unread. It goes without saying that it is much easier to point out these shortcomings than to remedy them.

A question is here raised, by way of suggestion, rather than of criticism, concerning one of the statements of the report. On page 76 it is said that the upper Mississippi probably assumed its present location in late Cretaceous time. There is some reason, though at present by no means conclusive, for suspecting that the present location of this stream was selected at a much later date, possibly as late as the Tertiary.[1] If it shall prove to be true that the isolated remnants of preglacial gravels, occurring at high levels at various points in the Mississippi basin are Tertiary, the development of the present physiographic features of the Mississippi basin, including the valley of the master stream, must date from a still later time. R. D. S.

Geologic Atlas of the United States. Folio 18, Smartsville, California, 1895.

This folio consists of four pages of text, signed by Waldemar Lindgren and H. W. Turner, geologists, and G. F. Becker, geologist in charge; a topographic sheet (scale 1:125,000), a sheet of areal geology, one of economic geology, and one of structure sections.

Topography.—The district of country represented lies between the

meridians 120° and 121° 30′ and the parallels 39° and 39° 30′, and embraces about 925 square miles, comprising a part of the foothill region of the Sierra Nevada. The elevation ranges from 50 feet above sea level in the northwestern corner to over 4000 feet in the northeastern corner. The topography is characterized by a number of parallel ridges, running in a north-northwest direction. The northeastern part has more the character of an irregular and undulating table-land. Through the ridges and the plateaus the watercourses have cut deep and narrow canyons. The Yuba River, with its branches, drains the larger part of the district. Honcut Creek on the north and Bear River on the south, are the only other streams of importance.

Geology.—Sedimentary formations occupy comparatively few areas in the district, all of which has been tentatively referred to the Calaveras formation, no fossils having been found in them. They consist of slates and quartzitic sandstones, usually with northerly strike and steep easterly dip. Diabase and porphyrite occupy large areas in the central and southern parts, as well as intrusive masses of granodiorite and gabbrodiorite. Amphibolites, resulting from the dynamo-metamorphism of diabase, gabbro, and diorite, also occur in several places. The rocks of the district are principally massive, in contrast to those of the districts adjoining on the south and east. However, two lines traverse it along which extensive metamorphism has taken place and schistose rocks have been developed. The superjacent rocks, resting unconformably on the older series, consist of Neocene river gravels together with beds of andesitic and rhyolitic tuffs. Comparatively small areas of these remain, the larger part having been carried away by erosion. Pleistocene shore gravels and alluvium occupy the southwestern corner. The Ione formation is not well exposed in this district, being in part covered by Pleistocene deposits, in part removed by erosion.

Economic Geology.—Important and rich Neocene gravel deposits in this district have been worked at Camptonville, Nevada City, North San Juan, Badger Hill, French Corral, and Smartsville. Gold-quartz veins occur scattered throughout the area, but by far the most of them are found in the immediate vicinity of Nevada City and Grass Valley. These districts are among the most important of the gold-mining regions in California. Many of the rocks of the district are adapted for building purposes. The only one in extensive use is the granodiorite near Nevada City. The often deep red soils in the foothill region are of

residuary origin. Extensive areas of alluvial and sedimentary soils are found only in the southwestern corner.

Sixteenth Annual Report, U. S. Geol. Survey, CHARLES D. WALCOTT, Director. Washington, 1896.

The report is issued in four volumes of which the first embraces the administrative reports and all papers of a theoretic nature. Among the latter are: "The Dinosaurs of North America," by O. C. Marsh; "Glacier Bay and its Glaciers," by H. F. Reid; "Some Analogies in the Lower Cretaceous of Europe and America," by L. F. Ward; "Structural Details in the Green Mountain Region in Eastern New York," by T. N. Dale; "Principles of North American Pre-Cambrian Geology," by C. R. Van Hise; "Summary of the Primary Triangulation Executed Between 1882 and 1894," by Henry Gannett. In part second, made up of papers of an economic character, are, among others, "Reports upon Cripple Creek," by Cross and Penrose, "A Reconnoissance across Idaho," by G. H. Eldridge, "A Report upon the Mercur Mining District," by J. E. Spurr, and a paper upon "The Public Lands and their Water Supply," by F. H. Newell. Parts three and four contain the matter formerly published separately in the series of volumes known as *Mineral Resources*.

Additional reviews and abstracts crowded out of this number will appear in the following issue.

THE

JOURNAL OF GEOLOGY

NOVEMBER–DECEMBER, 1896.

THE AGE OF THE AURIFEROUS GRAVELS OF THE SIERRA NEVADA.[1] WITH A REPORT ON THE FLORA OF INDEPENDENCE HILL.[2] [3]

It is the purpose of this paper to attempt to fix more definitely than has hitherto been done the age of the auriferous, detrital rocks of the Sierra Nevada, resting uncomformably on the bed rock series, generally at considerable elevations above the present drainage and covered by volcanic flows. This series is commonly designated as the "Auriferous Gravels." It is also the purpose to indicate briefly the more salient features of the Cretaceous and Cenozoic history of the Sierra Nevada. The results are the outcome of a study of the range between the parallels of 38° 30′ and 39° 30′, extending over a number of years, and are to be set forth more fully in a bulletin now in preparation.

The auriferous gravels have been carefully studied by Professor Whitney, who determined them as fluviatile deposits and assigned to them a Pliocene Age, basing his conclusions chiefly on the palæobotanical studies of Professor Lesquereux. At the same time Professor Whitney states that very probably auriferous gravels may have accumulated during the whole of the Tertiary period. On the maps of the United States Geological

[1] By WALDEMAR LINDGREN.

[2] By F. H. KNOWLTON.

[3] Published by permission of the Director of the United States Geological Survey.

Survey by Messrs. Turner and Diller and myself, the auriferous gravels have been indicated as "Neocene," including under this name the Miocene and the Pliocene. The same authors have correlated the lacustrine or brackish Ione formation along the western base of the Sierra with the fluviatile auriferous gravels on the flank of the range, and the two former authors have considered the age of both as probably Miocene,[1] basing their conclusions upon the more recent palæobotanical determinations of Professors Leo Lesquereux, Lester F. Ward, and F. H. Knowlton. Recently Professor Lawson[2] accepts Professor Whitney's determination of the auriferous gravels as Pliocene and thinks that the determination of the eroded surface on which rest the Ione formation and the auriferous gravels, as Miocene, may be in need of revision.

STRATIGRAPHIC RELATIONS OF THE AURIFEROUS GRAVELS.

The investigations of the United States Geological Survey have fully confirmed the earlier results as to the fluviatile character of the auriferous gravels over the whole flank of the Sierra Nevada above an elevation of a few hundred feet above the present sea level. Along the western base and at the northern end the auriferous gravels merge into brackish and lacustrine deposits. Along the western base the latter have been but little disturbed, while, according to Mr. Diller, they have experienced a considerable elevation at the northern end of the range. In a former publication[3] I have indicated the direction and the grade of the channels over a part of the western slope and investigated the character of the surface on which the gravels rest. The surface is that of a gently sloping, greatly eroded mountain range, but by no means reduced to a base level and not even to be considered as a peneplain. Only on the

[1] 8th Ann. Report U. S. Geol. Survey, p. 420.
14th " " " " " p. 466.
14th " " " " " p. 423.
American Geologist, Vol. XV, June 1895, p. 375.

[2] Bull. Dep. Geol., Univ. Calif., Vol. I, No. 4, p. 157.

[3] Bull. Geol. Sci. Am., Vol IV, p. 270.

middle and lower slopes of this range did the gravels accumulate.

In the principal broad Neocene river valleys one may generally distinguish the following formations:

A. The Ante-Volcanic Deposits.

1. *The deep gravels.*—These, usually hard and compact, coarse gravels fill the deepest trough-shaped depressions to a maximum depth of about 200 feet, usually 100 to 150 feet.

2. *The bench gravels.*—Covering the deep gravels and attaining a maximum depth of 300 feet, the bench gravels are spread out often to a width of one or two miles on the sloping shelves on both sides of the deepest trough. They are frequently very quartzose and more admixed with finer sediments than the deep gravels.

B. The Volcanic and Inter-Volcanic Deposits.

3. *The rhyolitic tuffs.*—Sweeping down the main river channels from the vents in the high Sierra, the flows of white rhyolite, accompanied by large masses of rhyolitic tuff, of clayey and sandy character, covered the bench gravels. These rhyolitic flows attain on the middle slopes a maximum depth of about 200 feet, while higher up they are much heavier. Much of this tuff is in the mining region designated as pipe-clay or chalk.

4. *The gravels of the rhyolitic period.*—The effects of the rhyolitic flows were to dam many lateral streams, thus causing immediate accumulations of gravels, clay, and sands. During the intervals between the rhyolitic eruptions the streams cut down new channels in the soft material and accumulated masses of gravel in their new beds. All these detrital masses of gravel, sand, and clay, generally of a finer character than the bench gravels, and usually containing rhyolitic pebbles, are designated as the "*gravels of the rhyolitic period.*" In many places, such as Nevada City, Nevada county, and the Long Canyon divide, Placer County, the rhyolitic gravels attain a thickness of several hundred feet.

5. *The gravels of the inter-volcanic erosion period.*—The interval separating the rhyolitic from the andesitic outbursts apparently differed in length at various points in the Sierra Nevada. While in some places, such as along the lower courses of the Middle and South Yuba, the andesitic tuffs lie almost conformably over the rhyolitic tuff, there are at other points, such as on the Forest Hill divide, near Placerville, and along the Mokelumne, indications of a relatively short period of a very active erosion, beginning immediately after the rhyolitic flows, or in some places shortly after the first flows of andesitic tuffs. This erosion was of a remarkably intense character, cutting sharp V-shaped canyons in new channels through the older beds, and in some places even down into the solid bed rock to a depth of about 100 feet. This action is so very different from that of the ante-rhyolitic and rhyolitic streams that the inference is justified that just after the rhyolitic flows the tilting of the slope took place, or at least began. In the bottom of these sharply cut channels a few feet of gravel accumulated along stretches with less grade, while, where the gorges were narrow and the grade steep no detritus is found. These are the gravels of the inter-volcanic erosion period.

6. *The andesitic tuffs and tuffaceous breccias.*—The andesitic tuffs poured down the river valleys in the form of successive mud flows of enormous volume, at first as sandy and clayey masses, but later mixed with a great quantity of larger angular or subangular fragments of hornblende and pyroxene-andesite, at last covering a large part of the slope and forcing the rivers to seek entirely new channels.

Along the valley border the Ione formation corresponds to the ante-volcanic bench gravels along the old rivers in the Sierra. The oldest or deep gravels of the river courses correspond to the fluviatile deposits in depressions in the surface on which rests the Ione formation; in other words, before the Ione transgression the rivers extended westward, probably to the center of the valley. The volcanic period is, along the valley border, represented by a series of gravels, sands, and tuffs spread over the Ione formation.

THE PALÆOBOTANICAL EVIDENCE OF AGE.

Almost the only means of determining the age of the auriferous gravels is afforded by the numerous plant remains which they sometimes contain. Remains of vertebrate animals have been found, but as Mr. H. W. Turner has pointed out, there is much doubt as to whether certain of the occurrences described by Whitney really belong to the auriferous gravels, so that this line of evidence does not at present lead to any satisfactory conclusions.

The age of the deep gravels.—No fossils of any kind have, as far as I am aware, been found in these beds. The coarse character of the gravels is largely responsible for this. As the bench gravels will be shown in the following pages to be of Miocene Age, the deep gravels are manifestly older, and some of them may be Eocene, but hardly older.

The age of the bench gravels.—The best and most extensive collections come from the upper part of the bench gravels, or from the very lowest part of the rhyolitic tuffs.

The Chalk Bluffs locality.—The largest collection examined by Professor Lesquereux was gathered by Mr. C. D. Voy, at Chalk Bluffs, near You Bet, Nevada county, and it therefore becomes desirable to indicate its exact horizon. You Bet is situated on the main channel of the Neocene South Fork of the Yuba, and the leaves occur at an elevation of about 3000 feet. The stratigraphic relations are extremely similar to those of Iowa Hill (Fig. 1) a little further south on the drainage of the old American River. There are the same deep gravels and heavy spreading bench gravels, capped by rhyolitic tuffs and andesitic tuffaceous breccia.

A bluff of the volcanic beds has been exposed by the hydraulic mining operations, and owes its name to the brilliant white color of the rhyolite. The exact locality from which the leaves came is a matter of some doubt, and is now covered by sliding débris. I was told by residents that they occurred at a place near the top of the bench gravels just below the rhyolitic

beds; on the other hand Professor Whitney states in his volume on the auriferous gravels that the matrix in which the fossils occurred was rhyolitic tuff. Professor Andrew Lawson kindly sent me some fragments of the matrix from the collection now preserved in the University of California. They are soft grayish to brownish compact clays which did not, under the microscope, give any evidence of volcanic origin; the extremely fine grain, may, however, have masked their original character. This much is certain that the fossils came from the uppermost bench gravels, or the lowest rhyolitic tuffs and about 500 feet above the bottom of the channel.

The Independence Hill locality.—In 1891 Dr. Cooper Curtice, on the request of Dr. G. F. Becker, visited many places in the gold belt to collect fossils. Among these were the Washington

FIG. 1. General cross-section at Iowa Hill.

gravel mine at Independence Hill, near Iowa Hill, Placer county. Mr. J. B. Hobson, the owner of the mine, first directed our attention to the occurrence. A very fine and extensive collection of fossil leaves was obtained. The leaves occur in a whitish or bluish consolidated clay or shale which at first is soft, but on exposure becomes moderately hard and brittle. This shale was interbedded with gravels near the base of the 200 feet high bluff produced by the hydraulic work. A glance at the section (Fig. 1) shows that the lower part of the bluff forms a part of the bench gravels (2) which again are overlain by rhyolite tuff (3) and gravels of the rhyolitic period (4). The fossils consequently come from the uppermost gravels of the ante-volcanic period. Professor Knowlton after making a careful study of this collection, remarks on it as follows: "Dr. Curtice's is the first large collection of plants that has been obtained from the aurif-

erous gravels since the material was collected which furnished the basis of Professor Lesquereux's investigations of this interesting flora. A number of smaller collections made from time to time by various members of the survey have also been studied by Professor Lesquereaux, but they were from isolated and separated localities and furnish comparatively little additional information as to the age of these deposits. The present excellent collection is therefore of special interest. The vegetable remains represented are in general very finely preserved and admit of careful and satisfactory study. Most of the species are represented by ample material and some of them, by a large series thus making possible a much more thorough biological study than could heretofore be made. Almost all of this material has been determined, the only portion remaining unidentified being a number of fragments and a few either with obscure impressions or with doubtful affinities.

The collection as outlined above, embraces fifty-six species of which number ten appear to be new to science. The new species belong to the following genera: *Ariscæmites*, *Ficus*, *Ulmus*, *Rhus*, *Zisyphus*, *Æsculus*, *Castanea*, and *Viburnum*.

These forms considered merely in the light of new species of course have little value in determining the age, but a more extended research through the literature on the subject than it has been possible to give at this time would undoubtedly bring out points of relationship or possibly of identity and they would then have a value as bearing upon the question of age. Until this can be done they must all be left out of consideration. As was to have been expected, a large number of the species were identified with those described by Professor Lesquereux in his paper on the flora of the auriferous gravels. Of the fifty-six species twenty have never been found in other deposits. Many of them were compared by Professor Lesquereux to living species and undoubtedly influenced him in deciding that the formation was of comparatively recent age. I have not had an opportunity of comparing these species myself, and until this can be thoroughly done they cannot be taken account of in the present connection.

Twenty species have also been identified in other formations, the six remaining forms making up the fifty-six species being of doubtful affinities. The following hastily prepared table shows the distribution of those forms.

TABLE SHOWING IDENTIFICATIONS OF FOSSIL PLANTS FROM INDEPENDENCE HILL, CALIFORNIA.

Species	Laramie	Laramie of California	Fort Union	Green River	Oligocene	Miocene	Pliocene	Remarks
Salvinia Alleni Lx.	..	..	..	×	..	..	..	Green River only.
Ficus tiliæfolia Lx.	×	..	×	×	×	×	×	
Ficus cf. *F. populina* Heer	..	..	..	×	..	×	..	
Ficus cf. *F. planicostata* Heer	×	..	..	..	..	..	..	Laramie only.
Ulmus Californica Lx.	..	..	..	..	..	×	..	
Populus Zaddachi Heer	..	..	..	×	..	×	×	¾ Miocene.
Castanea Ungeri Heer	×?	..	..	..	..	×	×	½ Miocene.
Juglans cf. *J. picroides* Heer	..	..	..	..	..	×	..	Miocene only.
Acer aequidentatum Lx.	..	..	..	×	..	..	×	
Viburnum tilioides Ward	..	..	×	..	..	..	..	Fort Union only.
Viburnum elongatum Ward	..	..	×	..	..	..	..	
Viburnum Whymperi Heer	×?	..	×	..	..	×	..	Miocene sp.
Cornus hyperborea Heer	..	×	..	..	..	×	..	¾ Miocene.
Aralia Whitneyi Lx.	..	..	..	..	..	×	×	
Persea pseudo Carolinensis Lx.	..	..	..	..	..	×	×	
Laurus Californica Lx.	...	..	..	..	..	×	×	California only.
Magnolia Californica Lx.	..	..	..	..	..	×	×	
Magnolia lanceolata Lx.	×?	..	..	..	..	×	×	

A study of this table shows that twelve species have been found in the Miocene in various parts of the world. Of this number five are almost exclusively confined to this horizon, and may be regarded as typical Miocene forms.

Only nine of the nineteen forms are found in the Pliocene, and two of these are from the so-called Pliocene of California and therefore have little weight. None of these nine species is confined to this horizon. It will be observed that five species are accredited to the Laramie ; of this number two are from Cherry Creek, Oregon, the age of which is only provisionally regarded as Laramie, the probability being that it is younger. Another species, *Viburnum Whymperi*, is doubtfully identified in the Laramie, being a characteristic Miocene species. A single

fragmentary leaf has been compared to *Ficus planicostata* Lx., a typical Laramie species, but the material is insufficient for a satisfactory determination. *Ficus tiliæfolia* Lx. has also been found in the Laramie at Golden, Colorado, but its principal range is in the Miocene and Pliocene.

Cornus hyperborea was found by Lesquereux in California in strata said to be Laramie, but the evidence seems insufficient and the horizon is much more likely to be later.

The Fort Union group is presented by no less than four species, three of them belonging to the genus *Viburnum*, and one to *Ficus*, while five species are found in the Green River group (Eocene) with one species (*Salvinia Alleni*) heretofore entirely confined to it. Two species have also been found in the Oligocene. From this tentative review it is seen that all of the species having a distribution outside of the auriferous gravels belong to formations of Pliocene or older age; none of them are more recent or living. The number wholly or mainly Miocene considerably exceeds the number found in any other horizon, and none of the species are apparently confined to the Pliocene. While the evidence is not yet sufficiently worked out to permit a positive statement, it seems to point very clearly to the Miocene Age of this deposit.

The following is a list of fossil plants found at Independence Hill. Quite a number are without doubt new to science, but as they have never been published I have simply given the generic name.

Salvinia Alleni Lx.
Arisæmites n. sp.
Ficus sordida Lx.
Ficus asiminæfolia Lx.
Ficus tiliæfolia Al. Br.
Ficus sp.
Ficus sp.
Artocarpus Californica Kn.
Ulmus Californica Lx.
Ulmus officinis Lx.
Ulmus pseudo-fulva Lx.
Ulmus n. sp.?
Ulmus fruit of.
Platanus appendiculata Lx.
Juglans egregia Lx.
Juglans sp.?
Hicoria ? fruit.
Salix Californica Lx.
Populus Zaddachi Heer.
Betula æqualis Lx.
Betula or *Alnus*, fruit.
Quercus convexa Lx.

Quercus distincta Lx.
Quercus elænoides Lx.
Quercus castanopsis ? Lx.
Quercus Boweniana Lx.
Castanea Ungeri. Heer.
Castanea n. sp.?
Castanopsis chrysophylloides Lx.
Corylus sp.
Magnolia lanceolata Lx.
Magnolia Californica Lx.
Liquidambar, fruit.
Acer æquidentatum Lx.
Acer fruit.
Rhus myricæfolia Lx.
Rhus dispersa Lx.
Rhus Boweniana Lx.
Rhus n. sp.
Æsculus n. sp.
Æsculus fruit.
Aralia Whitneyi Lx.
Aralia angustiloba Lx.
Laurus Californica Lx.
Persea pseudo-Carolinensis Lx.
Zizyphus piperoidas Lx.
Zizyphus n. sp.
Viburnum tilioides Ward.
Viburnum Whymperi Ward.
Viburnum elongatum ? Ward
Viburnum n. sp.
Viburnum fruit.
Cornus ovalis Lx.
Cornus hyperborea Heer.
Cornus n. sp.
Cercocarpus antiquus Lx.

This list, it should be remembered, is tentative and is likely to be modified by further collections or possibly to some extent by additional study.

The age of the Ione formation.—The flora found in the Ione formation is rather meager. North of 39° 30′ Messrs. Diller and Turner[1] have at several places found a scant flora considered by Professors Lesquereux, Ward and Knowlton to be of Miocene age and contemporaneous with the auriferous gravels. At Volcano hill, Placer county, H. W. Turner found fragments of leaves partly identical with those from Chalk Bluffs and Professor Knowlton considers them as probably Miocene.

In the Marysville Buttes, in the center of the Sacramento Valley I found a series of beds resting on the Tejon which I correlated with the Ione formation. In these a number of shells were found which Messrs. Stearns and Dall regarded as Miocene. The following forms were identified:

Crassatella Collina Conr.
Venericardia borealis Conr.
Verticardia ? sp.
Acila castrensis Hinds.
Macoma sp.
Tapes (Cuneus) sp.
Saxidomus sp.
Cardium modestum.

[1] J. S. Diller, Lassen Peak District, 8th Ann. Rep., U. S. G. S., p. 419. H. W. Turner, Rocks of the Sierra Nevada, 14th Ann. Rep., U. S. G. S., p. 462.

Liocardium apicinum Cpr.
Galerus sp.
Fusus (Exilia) sp.

Independently, however, of this flora and fauna the stratigraphic evidence connecting the Ione formation with the antevolcanic bench gravels is positively and unmistakably indicated, and the two can at numerous points be shown to run over one into another; thus south and north of Rocklin, Placer county, and at the mouth of the Yuba as well as north and south of the area here specially treated. As the bench gravels, the Ione formation is overlain by rhyolitic and andesitic tuffaceous beds.

Age of the rhyolitic tuffs and associated gravels.—These are but slightly younger than the bench gravels, but no flora has been studied from them unless that of the Chalk Bluffs be partly from that horizon.

Age of the gravels of the intervolcanic erosion period.—Leaves have been collected by Diller from Monte Cristo gravel mine, Spanish Peak, Plumas county, which are from a bed overlain by andesite and, according to Turner, pretty certainly later in age than the white quartz gravels, although not positively representing the period of the andesitic flows.[1] In Mohawk Valley Turner has collected leaves from the Neocene lake beds containing rhyolitic fragments and covered by andesitic tuffs. According to Professor Knowlton[2] these are closely related to the flora of the auriferous gravels. The leaves from Tuolumne Table Mountain are also, according to Turner, later than the auriferous gravels proper.

Among the localities described by Professor Whitney is Bowen's tunnel, Placer county, two miles north of Michigan Bluffs. Regarding this place, Professor Whitney writes, using the notes of Goodyear (Auriferous Gravels, p. 93). "The gravel averages a foot or two in the middle of the channel. Over the gravel is first a mass of 'chocolate'" (a brown consolidated clay, probably a volcanic mud) "from one to four feet in thickness; above this is the gray cement" (andesitic tuff)

[1] Am. Jour. Sci., June 1895.

[2] Fourteenth Ann. Rep., U. S. G. S., p. 466.

"similar to that of the Reed mine near Deadwood. This 'chocolate' contains leaves of deciduous and coniferous trees in tolerably good preservation." Now, Bowen's channel, correctly described above, is a typical example of the narrow valleys eroded shortly before the main andesitic outflows, and its flora is distinctly later than that of the Chalk Bluffs and Independence Hill and just antedates the main andesitic tuffaceous breccia flows. Lesquereux[1] describes the following species from this locality:

Quercus Boweniana Lx. Resembles certain living Mexican forms.
Rhus Boweniana Lx.
Zanthoxylon diversifolium Lx. Closely related to *Z. integrifolium* Heer (Swiss Miocene).
Acer vitifolium Al. Br. (Swiss Miocene).

The conifer leaves, mentioned by Whitney, do not appear to have been determined. Though meager, this flora is evidently closely connected, if not identical with that from the bench gravels and is probably Miocene. Still another locality mentioned by Professor Whitney is that of North Fork tunnel near Forest City, Sierra county. From the description of Professor Pettee (Auriferous Gravels, p. 437) it appears that the leaves found occurred in a sandy clay resting on a gravelly "cement" and directly covered by andesitic tuff. It is not quite clear whether by this "cement" is understood a volcanic tuff, but in any case it seems plain that the leaves could have antedated the andesitic tuff but a short time. This occurrence, which is considerably above the deepest gravels of the vicinity and not now accessible should probably also be connected with the inter-volcanic period of erosion. The elevation of this locality is nearly 5000 feet. The leaves are species of *Quercus* and *Acer* and Lesquereux remarks that it is Miocene by one species of Quercus and one of Acer, while it also has of each of these one species identical or closely resembling certain living Mexican forms.

While the flora of the gravels of the inter-volcanic erosion

[1] Report on the Fossil Plants: Appendix to WHITNEY'S Auriferous Gravels.

period is scant and no positive conclusions as to age can be drawn from it, it must be conceded that it is very closely allied to that of the bench gravels. While more extensive collections might show it to be of Pliocene age, yet the characteristic forms contained in it prove that up to the beginning of the rapidly succeeding andesitic flows there was no great change of climate.

Age of the andesitic flows.—Mr. Turner has at various points found fossil wood in the andesitic tuffs (Alpine county, elevation 7000 feet) which Professor Knowlton has identified as coniferous and designated as *Cupressinoxylon* and *Pityoxylon*.[1] No trees referable to the former genus occur at this elevation at the present time, from which it may be inferred that the climate during the andesitic period was milder than now.

To recapitulate, the deep gravels are probably of Eocene or Lower Miocene Age, the bench gravels and the rhyolitic tuffs are with considerable certainty of Miocene, probably Upper Miocene Age. The age of the gravels of the inter-volcanic erosion period and of the andesitic tuff is not established beyond doubt, but probably belongs to the lower Pliocene or Upper Miocene. The eroded surface upon which the auriferous gravels were deposited was consequently produced either during the earliest Miocene or during the Eocene.

It is of interest to note that Professor Knowlton in his extended studies of the floras of the Yellowstone National Park,[2] has found a flora which he calls the Lamar flora and refers to the Upper Miocene; this flora he states bears a very close resemblance to that of the auriferous gravels.

REVIEW OF THE POST-JURASSIC HISTORY OF THE SIERRA NEVADA.[3]

In the following lines a short summary is given of the different phases of the history of the Sierra Nevada between the

[1] Am. Geologist, Vol. XV, June 1895, p. 375.

[2] ARNOLD HAGUE, The Age of the Igneous Rocks of the Yellowstone National Park, Am. Jour. Sci., June 1896, p. 452.

[3] Unless otherwise stated, the results in this paper have only reference to the belt here studied. Many of them will be applicable to the whole range, but this needs confirmatory study.

parallels of 38° 30′ and 39° 30′. Space forbids in this place anything but a mention of the results attained.

The early Cretaceous.—The grand features of the initiation of the Cretaceous were the plication and welding of the Mariposa beds with the older sediments, active eruptions continued from the Jurassic period of the lofty volcanoes along the foothills, then the seashore, and the intrusion, in the foundations of the range, of enormous masses—batholites—of dioritic and granitic magma. Of the mountain range occupying the site of the Sierra Nevada at this time we know but little. The Sierra Nevada and the Great Basin were evidently not differentiated. A very active erosion planed down this range to a peneplain or at least to a comparatively gentle topography. At this time, probably shortly before the deposition of the Chico Cretaceous, the first break took place, separating the Sierra Nevada from the interior basin.

The orogenic disturbance was probably of a twofold character. It included the lifting up of the whole region between the Wasatch and the Pacific in arching form, and a simultaneous breaking in and settling down of the higher portions of the arch. Thus the Sierra Nevada crust fragment was formed, the larger part of which has ever since remained a comparatively rigid block. Along the eastern margin the system of fractures was outlined (see Fig. 2) which towards the close of the Tertiary was to be still further emphasized. The faults along these fractures were largely of normal character. The movement did not take place evenly along all of these faults, hardly any occurring in some places, while along other parts of the system the whole of the fault was confined to this time.

The main break occurred along a line extending from near Markleeville by Genoa up towards Reno, and the displacement reached a maximum of 3000 feet. The fault along the western side of Antelope Valley, which probably will prove to be continuous with the Mono Lake fault, also appears to have been broken at this time. But the large crust block west of this first mentioned line proved too great to sustain itself, and a large part

of it, bordered by parallel fault lines, sank down. This sunken area is now indicated by Lake Tahoe and by its continuation northward, the Sierra Valley, only separated from each other by masses of Tertiary lavas. The Tahoe-Sierra Valley "Graben"

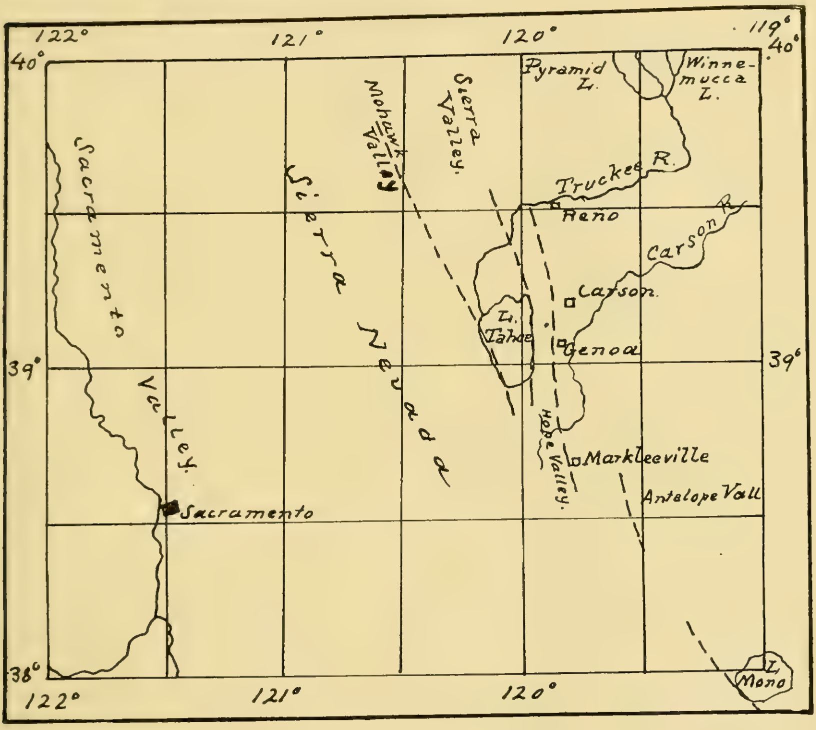

FIG. 2. Fault lines of the Sierra Nevada.

or "Moat" (the later word hesitatingly proposed as an English equivalent), is bordered on the west by the fault line beginning at Mt. Tallac, and extending by Donner, Independence and Weber lakes up towards Sierra Valley and Mohawk Valley. At this latter place the investigations of Mr. Turner indicate that the displacement may to a great extent at least be of Miocene Age. On the east it is bordered by the very distinct fault-line extending along the east side of Lake Tahoe up east of Boca and towards the east side of Sierra Valley. The long ridge between

the latter fault and the main break facing the Great Basin has very pronouncedly the character of a "Horst" or "Buttress" (the latter expression has been suggested by Mr. S. F. Emmons) — a block standing between two sunken areas.

This view then implies a gradual arching of the whole western part of the continent and a simultaneous sinking of parts of this uplifted crustal fragment, by reason of gravity, along longitudinal fractures. It is in close conformity with the previously announced views of King and Le Conte.

The newly formed block of the Sierra Nevada was at once attacked by the erosion; at first probably narrow canyons were cut in it, similar to those of today, though not so deep.

Chico period; close of the Cretaceous.—At this time the shore line along the western base advanced eastward and reached at least an elevation of 300 feet above the present sea level, possibly considerably higher. The Chico sandstones were laid down on an uneven surface, the foothills showing a relief at least as prominent as those of today. This important event is referred to as the Chico transgression.

The Téjon period (*Eocene*).—During the Chico and the Téjon the erosion was steadily at work on the flank of the Sierra Nevada, the first deep canyons were widened to broad valleys in the lower and middle parts of the range, while still preserving their character nearer the crest. There is no evidence of any Eocene deposits along the valley border in this latitude, though marine Eocene occurs in the Marysville Buttes in the center of the Great Valley and also further south on the east side of the San Joaquin Valley. Sediments of this age may have been deposited between 29° 30′ and 38° 30′, but if so, subsequent erosion has removed them. An important period of erosion certainly intervened between the Chico and the Miocene, and it is probable that the Eocene shore line was situated somewhere between the first foothills and the Marysville Buttes. This erosion has removed the greater part of the Chico sandstone, so that the Miocene along the valley border in part rests on older rocks, in part on fragments of Chico sandstone. While remov-

ing much of the Chico this Eocene erosion did not cut deeply into the underlying older series of crystalline rocks. Certain of the lower auriferous gravels underlying the Ione formation near the valley border may be Eocene or early Miocene, and the same age may be assigned to the deep gravels of the upper stream courses.

The early Miocene period.—About the time of the upper Eocene or the lower Miocene, then, the shore line had retreated far westward; this is directly indicated by the occurrence of heavy stream gravels brought up by volcanic agencies in the Marysville Buttes along with estuarine Miocene beds, correlated with the Ione formation. These gravels carry comparatively coarse gold. The slope of the Sierra had assumed the topographic character which the Miocene and Pliocene deposits have preserved for our inspection. The foothill topography of this old eroded surface consisted of comparatively rough ridges, the level tops of which indicated the old Cretaceous peneplain. The middle slopes consisted of broad, partly longitudinal valleys and comparatively gentle slopes in which the old peneplain is noticeable only in places, such as Banner Hill, Oregon Hill, Osborne Hill, and the tops of the hills of the upper Georgetown divide. The upper slope reaching up the divide, situated very nearly where it is today, on the west side of Lake Tahoe, consisted of rougher and deeper valleys, divided by more or less level ridges, indicating the old Cretaceous peneplain. English Mountain, the Black mountains, Snow Mountain, Duncan Peak, Granite Chief, indicate this Cretaceous peneplain in Nevada and Placer counties; Mt. Tallac, the Pyramid Peak range, Robb's Mountain and many others indicate the same in El Dorado county. The relation of the two eroded surfaces, the Cretaceous and the Miocene, is clearly discernible from any point in the lower foothills looking up toward the summit of the range. Above the deep canyons of the modern gorges extend the broad, flat lava plateaux capping the separating ridges and looking very much like an old base level. These lava flows cover the comparatively gentle topography of the Miocene valleys. Above them rise the peaks

and ridges just mentioned, and indicate with their level sky line the extend of a far older eroded surface, uplifted and dissected long before the auriferous gravels were deposited or the lava flows extruded.

The later Miocene period (*the Ione formation*).—This is the period of the auriferous gravels *par excellence*. Stream gravels had already formed to some extent in the lower reaches and deepest parts of the river valleys, but the greatest masses were accumulated during this period.

The shore line again moved eastward up to an elevation of at least 400 feet above the present sea level and a heavy series of sediments was laid down along the foothills which rose with decided relief above the waters of the gulf; this may be referred to as the Ione transgression. Only in the northern and middle part of the range did the gravels attain their maximum depth. One of the probable causes leading to their deposition has been indicated by Mr. J. S. Diller,[1] who holds that disintegration exceeded transportation at the close of the Eocene and beginning of the Miocene, and that consequently the surface was covered with a deep mantle of decomposed material; during the Miocene a slight uplift increased the erosive power of the streams and swept the detrital matter into the river courses. This is very probably a correct explanation, although perhaps not the only one. It seems that the steep foothill ranges may have acted the part of barriers restraining the gravels in the valleys of the middle slopes. To this the heavy accumulations along the American and Yuba River on the middle slope is in part due.

Close of the Miocene; beginning of the Pliocene. The eruption of rhyolite and andesite near the crest of the range closed the gravel period. At some time during the volcanic period, probably in the interval between the rhyolitic and the andesitic flows, occurred a new break along the eastern base of the Sierra. The principal movement in this latitude took place along the old fault-line extending from Verdi, Nevada (ten miles west of Reno), down towards Markleeville, while along the fault-lines

[1] 14th Ann. Report U. S. G. S., p. 427.

on both sides of Lake Tahoe little or no movement seems to have taken place. Near Verdi the displacement was probably smaller than further south. There is, along the first line, excellent evidence of the amount of the displacement. It probably did not much exceed 2000 feet, while the aggregate amount of both the late Cretaceous and the Miocene displacement is about 5000 feet near the latitude of the little town of Genoa, south of Carson. The best evidence of this displacement is found in the drainage of the West Fork of the Carson River, which from a meandering course in Hope Valley, in Alpine county—the topography of which accurately represents the pre-volcanic Miocene surface—breaks through the eastern scarp in a wild canyon of extremely steep grade, to again resume its meandering course in the Carson Valley 2000 feet lower.

Near the crest the range is at many places, as first pointed out by Dr. G. F. Becker,[1] intersected by a system of joint planes on which small movements have taken place, which may aggregate to considerable amounts. These joint systems, which probably were produced about the close of the Neocene, appear to accompany and supplement the large normal faults at the eastern base.

To sum up, the topography about Lake Tahoe has remained similar to its present form probably since the close of the Cretaceous, while a late Miocene or Pliocene fault of 2000 feet has been formed along the east side of the buttress lying to the east of Lake Tahoe. The displacement here indicated is less by several thousand feet than that shown by the grade of the Neocene rivers as outlined in a previous paper; this strengthens the belief that we have here to deal with a composite movement, one upward affecting a large area, and one downward consisting of local sinking of moats. In comparing this region with that north of 39° 30′ it should be borne in mind that, according to the best evidence, the northerly part during the gravel period stood at considerably lower elevations than the section about Lake Tahoe, as indicated among other things by the absence of

[1] Bull. Geol. Soc. Am., Vol. II, pp. 49–74.

gravels at the latter vicinity and the abundant occurrence of them northward. The relative post-Miocene uplift has consequently been larger northward. During the gravel period a drained lake probably occupied the Tahoe-Sierra Valley moat. During the volcanic period Tahoe became separated from Sierra Valley by masses of andesite. Separate lakes covered Sierra Valley, the Boca-Truckee Valley, Tahoe and Mohawk valleys. Carson Valley east of the Genoa buttress was also occupied by a lake during the volcanic period, as was the vicinity of Verdi and Reno. During the tilting of the Sierra Nevada that crustal block did not act as a rigid mass, but was slightly deformed and arched, as indicated from a study of the Neocene river grades.[1]

Along the western foot of the range a retreat of the shore line occurred during the andesitic eruption as indicated by the unconformity separating the andesitic beds from the Ione formation and by another dividing the Pleistocene from the Ione and the volcanic beds.

The Pleistocene period.—The last andesitic flows are supposed to mark the close of the Pliocene in the Sierra Nevada. This is a somewhat uncertain line as to its exact age, but it is the only one which can be drawn without creating artificial distinctions. It is true that in referring the Ione formation to the Upper Miocene and drawing the line between the Neocene and the Pleistocene at the close of the tuff and breccia flows, the line limit allotted to the Pliocene becomes somewhat restricted, the volcanic period, as above observed, being of comparatively short duration. It is not improbable that the earlier part of the Pleistocene of the Gold Belt maps includes some of the Pliocene as outlined at other localities in the United States. The Pleistocene of the Gold Belt maps includes one long period of extremely active erosion, chiefly characterized by canyon-cutting; during this time another advance of the shore line took place; the Great Valley being at this time a lake, the highest elevation of whose shores, well marked by bodies of gravel, extended 400 feet above

[1] Two Neocene Rivers, Bull. Geol. Soc. Am., Vol. IV, p. 297.

the present sea level. Mr. L. F. Ransome[1] has expressed a belief that the Great Valley during the early Pleistocene was chiefly above water, though transient lakes might have existed. An extensive acquaintance with the formations along the Sierra foothills can hardly fail to convince anyone of the reality of the Pleistocene body of water extending up to the level indicated, though for the later part of the Pleistocene after the drainage of the lake by the subsidence of the region about San Francisco,[2] Mr. Ransome's view is probably correct. A subsidence of only 50 feet would at the present time create a very large lake in the valley.

During the earlier and middle Pleistocene many minor eruptions of basalt took place, chiefly near the crest of the range. Lake Tahoe had first been dammed up by andesite during the latter part of the Neocene and during the earliest Pleistocene, its outlet, the Truckee River, cut a canyon through the andesite and through the northern continuation of the great buttress east of the lake. In middle Pleistocene time this canyon was again dammed up by a basaltic eruption, and again the lake cut an outlet through this second dam.

The second division of the Pleistocene period comprises the glaciation of the High Sierra, the drainage of the lake of the Great Valley and corresponding formations of fluviatile deposits.

During the glacial period the whole crest-region of the Sierra was covered with a continuous sheet of ice, *névé* and snow from which glaciers extended down along the principal river courses. The glacial basins were swept bare, the morainal débris accumulating at lower elevations, around the projecting ice tongues. The block east of Lake Tahoe and in fact the whole eastern slope was only glaciated to a small extent. The outlet of Lake Tahoe, the canyon in andesite between Tahoe City and Truckee City, has apparently never been filled with glaciers though ice streams from lateral canyons reached it in one or two places. Lake Tahoe does not appear to have been filled with glacial ice at any time.

[1] Bull. Dept. Geol. Vol. I, No. 14, p. 386.

[2] Cf. A. Lawson, Univ. Calif. Bull. Dept. Geol. Vol. I, No. 8, p. 266.

The largest glaciers were found on the headwaters of the Yuba and the American rivers. The lowest elevation at which glacial traces have been found on the western slope is about 3500 feet. The third period, the present, is marked by the disappearance of the glaciers and by the continued formation of fluviatile deposits in the Great Valley.

It is not believed that, during the early Pleistocene any marked orographic changes took place along the eastern base of the Sierra. In very recent times—after the glaciation—a renewed faulting is noticeable at many places, such as at Owen and Mono lakes and near Genoa south of Carson, Nevada. At the later place the displacement is about 40 feet. Very strong springs, many of them hot, are located along the foot of the scarp, which is extremely sharply marked. As at Mono Lake[1] the deepest depression—here the Carson River—closely hugs the escarpment for considerable distance in spite of the active erosion and the large amount of material transferred to the valley from the escarpment. This appears to be a strong argument in favor of the view that the eastern block—the Carson Valley—is sinking, instead of the western block—the mountain scarp—rising.

The similarity of these conditions with those at the foot of the Wasatch, so admirably described by Mr. G. K. Gilbert, certainly appears very striking.

Recently Mr. F. L. Ransome has published an interesting criticism of the theory of isostacy as applied to the interior valley of California,[2] in which he arrives at the conclusion that the facts do not support the theory, in the case of the Great Valley, a conclusion which appears well justified. Mr. Ransome's argument could, however, have been made much stronger. From the above, it is clear, that there have been at least three important transgressions separated by unconformities, representing periods of erosion, since the end of the Cretaceous. The rivers sometimes extended far into the valley, while at other times the

[1] I. C. Russell, U. S. G. S., 8th Rep., pp. 261–394.

[2] Univ. Calif., Bull. Dep. Geol., Vol. I, No. 14, pp. 371–428.

shore line moved far eastward. Subsidence has certainly not kept equal pace with deposition in the Great Valley.

CORRELATION WITH THE BEDS OF THE COAST RANGES.

In a recent bulletin of the Geological Department of the University of California, Professor Lawson has described the Miocene, Pliocene, and the Pleistocene from various points along the coast, calling especial attention to the evidence of recent elevation as attested by the numerous beach lines at elevations up to 1200 feet.[1] He has further described the Merced series from the San Francisco peninsula and the Wildcat series from the northern coast, identifying both as Pliocene, and deposited during the gradual subsidence of the coast preceding the recent uplift, marked by the beaches. He finds that the Miocene, as represented by the Monterey series is distinct from the Pliocene as represented by the Merced formation, and that the latter is separated from the former by a long period of depression. The Pliocene and the Pleistocene gradually merge into one another, and the somewhat arbitrary line between the two should be drawn at the upper part of the Merced series at a time when the shore line began to recede westward. In short,

[1] Bull. Dept. Geol. Univ. of Calif., Vol. I, No. 4, p. 148. Professor Lawson, in demolishing Professor Davidson's view of the beaches along the coast of California as formed by ice action, states that the only geologists who have observed and correctly interpretated them are Dr. Cooper (Geol. Cal., Vol. I, p. 184), in his observations on San Clemente Island, and A. Bowman, in describing the coast in the vicinity of San Francisco (Proc. Cal. Acad. Sci., July 1, 1872). This is evidently not quite correct. No geologist could for a moment mistake those beach lines, so plainly are they indicated, and we find, for instance, that W. P. Blake (Pac. R. R. Rept., Vol. V, p. 187) recognized a raised beach 300 feet above the sea at Monterey, and a general elevation of the coast. Dall found evidence of a post-Pliocene uplift of 600 feet in the vicinity of San Diego (Proc. U. S. Nat. Museum, 1878, Vol. I, p. 3). Mr. G. F. Becker recognized a recent elevation of the coast of at least 250 feet (Monograph XIII, U. S. G. S., p. 207) on the Sonoma coast. In 1888, in a paper on the Geology of Baja, California, by W. Lindgren (Proc. Cal. Acad. Sci., 2d ser., Vol. I, Part 2, p. 179) the terraces are referred to as follows: "The numerous oscillations of the shore line during post-Pliocene time are equally plain in Lower California, as along the coast north of it. . . . . The ancient shore lines are shown on Punta Banda (60 miles south of the Mexican line) as often well marked wave-built terraces;" four beaches were recognized, the highest at an elevation of 600 feet.

the history of the coast ranges in later geological times would be as follows:

Miocene depression.

Post-Miocene uplift and long period of erosion.

Pliocene depression; filling of valleys and truncation of the mountain to an approximate peneplain; archipelagic coast line.

Pleistocene uplift; beach lines.

The age of the beds has been determined by their molluscan remains, a line of evidence not altogether satisfactory where Tertiary and recent beds are concerned as has been pointed out among others by Professor Lawson[1] and also by Professor W. H. Dall.[2]

The question now arises how the beds along the foot of the Sierra Nevada should be correlated with the beds of the coast ranges. Dr. Lawson, without hesitation, correlates the Merced series with the auriferous gravels of the Sierra Nevada,[3] accepting Whitney's determination of them as Pliocene.

It has been shown in the preceding pages that the upper part of the ante-volcanic auriferous gravels correspond to the Ione formation, and both have on palæobotanic grounds been referred to the upper Miocene. It has also been shown that the flora of the volcanic period very closely resembles that of the Ione formation. A very similar flora has been described by Lesquereux from Corral Hollow and Kirker Pass near Mount Diablo, on the western side of the valley.[4] The beds rest in apparent conformity on Miocene carrying *Ostrea titan* Conrad, are associated with molluscan forms determined by Gabb as Pliocene from the twenty-one species identified; and are capped by detrital andesitic beds.

The characteristic feature of this flora of the Ione and the auriferous gravels is that it is related in its general characters to that of a subtropical moist region analogous to the northern coast of the Gulf of Mexico. It contains genera such as

[1] Bull. Dept. Geol. Univ. Calif., Vol. I, p. 57.

[2] Bull. 84, U. S. G. S., p. 195.

[3] Bull Dep. Geol. Univ. Calif., Vol. I, No. 4, p. 157. See also Vol. I, No. 1, p. 56.

[4] H. W. Turner, Geol. Soc. Am. Bull., Vol. II, pp. 383–402.

Quercus, Ficus, Juglans, Magnolia, Persea, Laurus, Cinnamomum, Paliurus, Zisyphus, etc. Contemporaneously with this flora the salt water extended eastward as far as Mount Diablo and northward probably as far as the Marysville Buttes.

There are some remains of plants in the Merced series, described by Professor Lawson.[1] At the very base rests, on Mesozoic volcanic rock, a stratum of partly carbonized forest material from which abundant pine cones were collected; these were determined by Professor E. L. Green as *Pinus insignis* (Monterey pine), a species not widespread at the present day, but still growing abundantly dear Monterey; about the middle of the series little altered trunks of trees occur associated with cones determined as *Pseudotsuga taxifolia* (Douglas spruce), a species common in California at the present time. It is scarcely permissible to correlate these two floras. In the auriferous gravels there is not one species, according to Professor Knowlton, which can be undoubtedly identified with living forms, and moreover, the coniferæ are sparingly represented. Even conceding the possibility of a slightly cooler climate on the immediate seacoast, Professor Knowlton[2] does not believe that these two different floras could have existed at the same time and in so close proximity to each other.

The correlation of the Merced and Wildcat series with the auriferous gravels does not then appear permissible. It seems that in the maps of the valley border of the Sierra Nevada, the arbitrary line between the Neocene and Pleistocene has been drawn considerably lower than the similar arbitrary line established by Professor Lawson at the top of the Merced series. In other words the Pleistocene as defined on the gold belt maps, occupies a considerably longer time than the Pleistocene on the coast as defined by Professor Lawson. The Merced series is probably contemporaneous with the early Pleistocene of the valley border.

A detailed examination of the western valley border in the vicinity of Corral Hollow and Kirker Pass would greatly eluci-

[1] Bull. Dept. Geol. Univ. Calif., Vol. I, No. 4, pp. 143, 144.

[2] Oral communication, February 1896.

date the question. Stratigraphic, floral and faunal evidence should as much as possible be considered together to obtain correct results.

SUMMARY OF POST-JURASSIC GEOLOGICAL HISTORY.

Cretaceous	Basic eruptions along foothill volcanoes, continued from the Jurassic period. Folding of the Mariposa beds. Intrusion of granitic and dioritic batholites. Pre-Chico erosion, continued to approximate peneplain. Pre-Chico uplift and break along eastern edge. First differentiation of the Sierra Nevada. Sinking of the Tahoe-Sierraville moat. Dissection of the uplifted peneplain. Chico transgression.
Eocene	Retreat of Shore line ; Téjon erosion along valley border and gradual degradation of the Cretaceous peneplain.
Miocene	Miocene (Eocene?) deep gravels. Heavy Bench gravels. Ione transgression along valley border.
Miocene? Pliocene?	Rhyolitic eruptions and continued accumulation of gravels. Late Neocene uplift and faulting along the eastern edge of the range. Retreat of shore line ; short but active period of erosion.
Pliocene	Principal andesitic eruptions ; lakes in the Tahoe-Sierraville depression and along the eastern slope.
Pleistocene	Early Pleistocene lake in the Great Valley and very active dissection of the uplifted Miocene surface. Basaltic eruptions. Glaciation and lakes along the eastern slope. Gradual retreat of the glaciers and lakes. Recent breaks along eastern fault-line. Fluviatile deposits in the Great Valley.

WALDEMAR LINDGREN.

THE ANORTHOSITES OF THE RAINY LAKE REGION.

A NUMBER of eruptive masses rising through the Keewatin (Huronian) schists and schist conglomerates of the Rainy Lake region in western Ontario were mapped and described by Professor A. C. Lawson in 1887, the most interesting group of eruptives occurring along the southern shore of Seine Bay and between Bad Vermilion and Shoal lakes, just to the east.[1] Here very basic and very acid rocks are found associated. The acid members of the group, quartzose granites containing much plagioclase, have been studied somewhat carefully from the fact that they contain important gold-bearing veins, but the barren anorthosites have been neglected. The soda granites, which often weather into the greenish sericite variety, protogine, and have been sheared and metamorphosed into sericitie schists near the quartz veins, have been described by Winchell and Grant[2] and the present writer,[3] and need no detailed mention here. The basic rocks of the group, briefly described as saussuritic gabbro by Lawson, but afterward identified by him as anorthosite,[4] deserve some further mention.

The largest area of anorthosite encloses the southern arms of Bad Vermilion Lake, and surrounds or is bordered by three areas of eruptive granite. Two or three miles to the west, on Seine Bay, a series of points and islands of anorthosite extend, with some interruptions, westward along the southern shore of the bay for about ten miles. The rock is generally white, almost like crystalline limestone, with only a very small proportion of darker minerals occupying spaces between more or less perfect phenocrysts of plagioclase which range in size from a

[1] Geol. Sur. Can., Part F, 1887, pp. 56 and 99.

[2] WINCHELL and GRANT, Geol. Nat. Hist. Sur. Minn., 23d Ann. Rep., pp. 58–60.

[3] Ontario Bureau of Mines, 1894, p. 89.

[4] Geol. Nat. Hist. Sur. Minn., Bull. No. 8, 1893, 2d part, p. 7.

quarter of an inch to a foot in longest diameter. Towards the western end of Bad Vermilion, however, there are points where the green constituent becomes more important, and the rock may be called a porphyritic gabbro.

Frequently portions of chloritic or sericitic schist have been enclosed by the anorthosite, showing its post-Keewatin age; and occasionally a green massive rock, apparently weathered diabase, is seen, probably portions of massive Keewatin rocks swept off by the molten anorthosite.

The rock, though clearly an anorthosite, presents some points of difference from the typical rocks of the name, so well described by Dr. Adams from the province of Quebec, the feldspars being always white, never purplish in color, and comparatively rarely showing the sheared and granulated character so often found in eastern Canada.[1] The marked tendency toward idiomorphism in the feldspars is apparently unusual in other regions. The loss of the purplish color is no doubt the result of weathering, which has generally progressed rather far, though cleavage surfaces showing twin striations can be found generally. The freshest example studied comes from a hill at the mouth of Seine River.

In the numerous thin sections examined more than nine-tenths of the rock is seen to consist of plagioclase, usually sprinkled with zoisite particles or more or less completely changed to a saussuritic mass. The darker portions lying here and there in angles between the feldspars consist mainly of a fibrous or scaly mineral with parallel or nearly parallel extinction and low double refraction, probably serpentine, but perhaps a member of the chlorite group. Augite was found as a remnant only once, and then was not of the diallage type. No other primary minerals were observed, not even magnetite; and very few secondary ones require to be added to those mentioned, only epidote, probably some albite, and a very little calcite. The feldspars, where fresh enough to study, show broad

[1] Ueber das Norian, Separat Abdruck, Neues Jahrbuch für Min., Beilageband VIII; and Can. Rec. Science, Vol. VI, No. 4, p. 190.

twinning according to the albite and frequently also the pericline law, the former ranging in angle of extinction from the twin plane between 17° and 37°. The average extinction angle in thin sections from Bad Vermilion Lake is about 24°, and from the mouth of Seine River 32°. The former feldspar is therefore bytownite and the latter anorthite, both more basic than that of the typical anorthosite, which Dr. Adams finds to be labradorite.

In the freshest section studied (783, mouth of Seine River) the large interlocking feldspar individuals often show a thin band of fresh, clear feldspar where one joins the other; and this clear feldspar strip is seen, when examined with a high power, to form a secondary enlargement of the adjoining crystals, the twin striations running out into it. The extinction angles of these secondary feldspar rims vary from 8° to 14°, corresponding to labradorite, so that the later feldspar is more acid than the older. In one case a bytownite crystal has been broken, the parts slightly shifted, and then cemented with labradorite, most of the twin lamellæ running across the strip of cement.

An analysis of a specimen from the mouth of Seine River was made by Mr. William Lawson in the laboratory of the School of Practical Science, Toronto, the results being given in column No. I. In No. II an analysis of anorthosite from Rawdon, Que., made by Sterry Hunt and quoted by Dr. Adams is given for comparison.[1] No. III gives the results of an analysis of granite adjoining the Bad Vermilion anorthosite area, and is the work of Mr. Lawson.

	I	II	III
SiO_2	46.24	54.45	76.20
Al_2O_3	29.85	28.05	14.41
Fe_2O_3	1.30	0.45	....
FeO	2.12	....	1.49
MnO	trace	....	....
CaO	16.24	9.68	2.19
MgO	2.41	....	0.65
Na_2O	1.98	6.25	3.32

[1] Ueber das Norian, p. 494.

	I	II	III
K_2O - - - - - -	0.18	1.06	2.44
Co_2 - - - - - -	1.03	(H_2O) 0.55	....
	101.35	100.49	100.70
Sp. Gr. - - - - - -	2.85	2.69	2.65

The low percentage of silica and soda, and the high percentage of lime as compared with the anorthosite from Quebec are notable and correspond to the results of microscopic examination, the specimen from Seine River consisting chiefly of anorthite, and that from Rawdon of labradorite. The specific gravity, 2.85, is very high, perhaps because of the presence of considerable zoisite. The specific gravity of a specimen from Bad Vermilion Lake was determined to be 2.76, corresponding to its slightly more acid character, since it consists of bytownite.

The results of the analysis show that the anorthosite from the mouth of the Seine is one of the most basic of the massive rocks, having about 8 per cent. less silica than the typical rocks of eastern Canada, but it is probably wiser to include it among the anorthosites, since the somewhat more acid rock from Bad Vermilion Lake links it to the eastern ones.

It would perhaps be most logical to name the whole series of rocks consisting essentially of plagioclase anorthosites or plagioclasites,[1] adopting a binomial nomenclature like that tacitly admitted in the classification of other rocks, such as the granites. We should then speak of anorthite, bytownite, and labradorite anorthosites or plagioclasites; and the list might require to be extended to include andesine and oligoclase rocks, perhaps also albite rocks. The albitites described by Turner from California, under the head of syenites, are dike rocks apparently and should perhaps not be classed with the plutonic rocks referred to here.[2] The name anorthosite has priority but has a very tautological sound in the term describing the rock just discussed, anorthite anorthosite.

Lawson looks on the anorthosite and granite areas of Bad

[1] See Viola as quoted by Rosenbusch in Massige Gesteine, Erste Hälfte, p. 298.

[2] American Geologist, June 1896, p. 379, etc.

Vermilion Lake as representing the truncated base of a Keewatin volcano which served as one of the vents for the pyroclastic materials so widely found in the Keewatin rocks of the region, the basic rock coming first and the acid afterwards.[1] In this he is probably not correct, for there is good evidence to show that the anorthosite, which probably solidified under a considerable thickness of superincumbent rock, was so far exposed by denudation that fragments of it could be rolled into bowlders and become part of a conglomerate before the eruption of the granite. The latter rock has sent apophyses into the anorthosite and has pushed its way through a schist conglomerate containing pebbles and bowlders of quartz-porphyry, sandstone, green schist and occasionally also anorthosite quite like some facies of the adjoining mass. Apparently a long interval separated the anorthosite eruption from that of the granite. The sharp segregation of a magma into a basic anorthosite and a very acid granite would in any case be rather surprising.

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School of Science,
Toronto.

[1] Geol. Sur. Can., loc. cit.

THE MECHANICS OF GLACIERS. I.[1]

1. *Law of flow.*—If we consider the ice flowing through two cross-sections of a glacier, it is evident that for a glacier in equilibrium, that is, one neither increasing nor diminishing in size, the quantity flowing through the lower section must equal that flowing through the upper one diminished by the quantity melted between them, if we are in the region of melting (the dissipator); or increased by the quantity of ice accumulated between the sections, if we are in the region of accumulation (the reservoir). Keeping the upper section at the névé-line and moving the other one down the glacier, the melting area between the sections increases and therefore the flow through the lower section becomes less. Now placing the lower section at the névé-line and moving the upper we see that the amount of accumulation between the sections increases, and consequently the flow through the upper section diminishes, as we move it higher up the reservoir. If we keep our two sections at a fixed distance apart, and move them to different parts of the glacier, the difference of the flow through the sections must increase as we go down the dissipator, because the rate of melting increases, and must increase as we go up the reservoir because the accumulation increases. We can say then that *the greatest flow occurs through a section at the névé-line and diminishes as we go up or down the glacier from there;* and, moreover, that *the rate of diminution of the flow becomes greater the further we go from the névé-line.* This is the *law of flow*, and is perfectly general; it depends only on the law of the indestructibility of matter, and the observed facts that the ice of glaciers moves, and that there is accumulation above, and dissipation below, the névé-line.

The steeper the dissipator's slope the more rapidly will the

[1] Read before the Geological Society of America, at the Philadelphia Meeting, December, 1895.

rate of melting increase as we go down the glacier, and the more rapidly will the flow diminish; similarly, the steeper the reservoir the more rapidly in general will the flow diminish as we ascend.

It has been stated as an empirical rule that the velocity of the ice of glaciers lying in beds of uniform slope is greatest in the neighborhood of the névé-line and diminishes as we leave it going up or down the glacier. This rule is, like most empirical rules, subject to exception, and may be stretched beyond its limit, as when Professor Heim (Gletscherkunde, p. 160) attempts to account for the increased velocity near their ends of some Greenland glaciers which break off in bergs, by saying that we have here to do with only the upper part of the glacier; whereas, in reality, the ends are some distance below the névé-line. The general law that the flow is less below, than at, the névé-line must hold; this flow equals the product of the average velocity by the sectional area by the effective density. The more rapid surface velocity is permitted by the formation of immense crevasses which reduce the effective density of the upper 200 feet of the ice by perhaps a half. The real and sufficient cause of this increase in velocity is the lack of support in front, which Professor Heim also describes. The flow near the end of such glaciers is not as large as appears at first sight; it is only the upper part of the ice that has such an abnormal velocity; the lower part, being supported by the pressure of the water, must have a velocity not differing very greatly from what it would have if the glacier completed its course and ended as an ordinary alpine glacier. Indeed, as the increasing velocity at the surface is only permitted by the opening of immense crevasses, so an increasing velocity in the middle and under part of the glacier would also be accompanied by similar openings; and the whole body of the ice would be so torn by these great fissures, that comparatively thin sheets would be broken off from the glacier's end, and large icebergs could not be formed. The drag of the upper layers over the lower ones, would, in glaciers whose ends are floating, have to be entirely

balanced by the cohesion of the lower ice-layers, as there is no friction against its bed.

The empirical rule does not cover the case of a glacier like the Mer de Glace, where the bed becomes steeper near its end, causing a more rapid motion. But the law of flow must hold; here again the effective density of the ice is reduced by the opening of wide crevasses, and the sectional area is undoubtedly less than it would be if the slope of the glacier's bed continued uniform.

In the case of glaciers with beds of uniform slope, the velocity and flow increase and decrease together, though not in the same proportion.[1] If we had a glacier of indefinite length and of uniform section, it is evident that the direction of flow would be parallel with the slope, and the velocity along any line parallel with the glacier's axis would not vary as we move along the direction of flow. To calculate the forces acting on a section of such a glacier we have only to consider the weight of the section, the viscosity of the ice and the friction against the bed. The motion consists of two parts: (1) the sliding on the bed, of which we have hardly any knowledge; (2) the shearing of the section by virtue of which $A\,B$ (Fig. 1) would be deformed into $A'B'$. Let us call the velocity of a point under such conditions the *normal velocity* corresponding to that particular form and size of the cross-section.

A glacier of uniform section could not exist if there was any melting; for we have seen that in this case the flow would become smaller as we go down the glacier, and with uniform section this would require a decreasing velocity, which, however, is not admissible; for, from the supposed uniformity of the glacier, every section would be subject to the same forces and would move with the same velocity. Therefore, the slope of the

[1] The remainder of this section and all of the next are based on the theory that the ice of glaciers acts in general like a viscous substance, and that the sole cause of the motion is the weight of the ice itself. I am not discussing the physical nature of ice which gives it this viscous property. Similar conclusions might be reached on other theories. The rest of the paper is only dependent on the observed phenomena of glaciers.

glacier being uniform, wherever there is melting the cross-section must change so as to produce a smaller flow as we descend the glacier. For glaciers which fill narrow valleys this simply means a diminution in both the breadth and thickness of the glacier; but for those which spread out, like the Davidson glacier in Alaska, the flow is diminished by the smaller thickness, in spite of the increased breadth.

We may infer a similar thinning of the glacier above the névé-line; indeed, with many glaciers, the great breadth of the reservoir, notwithstanding the smaller density of the ice, requires a very small depth in order that the flow should not be too great.

If we look upon the ice-sheet, which covered North America, diagrammatically as radiating from a center, and suppose that the annual accumulation and melting per unit surface were proportional respectively to the distance inside and outside of the névé-line, we find, in order that total melting and accumulation should be equal, that the névé-line would have been at about two-thirds of the distance from the center to the circumference of the circle. It is probable, however, that the melting was larger at the edge, and the accumulation less at the center than this, and, therefore, that the névé-line was nearer the circumference. The greatest flow was of course through a section through the névé-line, and the greatest velocity must have been somewhere in the same neighborhood.

Pressure.—Let us see if the different parts of a glacier, gradually thinning out to its ends, can have the *normal velocities* due to their cross-sections. We know next to nothing about the sliding of the ice over its bed, but we are safe in assuming that the normal velocity of sliding would be no greater in a thin than in a thick section.[1]

Consider then that the bottom velocity of the region between the two sections *AB* and *CD* of the dissipator is uniform (Fig. 1). For the sake of simplicity we will consider the thickness of the

[1] The only experiments bearing on this point are those of HOPKINS (*Phil. Mag.*, London, 1845, Vol. XXVI, pp. 3–6). By means of a wooden frame he held together a

glacier small in comparison to its breadth. After a certain time the sections would be deformed to $A'B'$ and $C'D'$, if the ice moved everywhere with its normal velocity. The slope of the deformed section at any point would depend only on the weight of the ice above that point, *i. e.*, on its depth below the surface of the glacier, and therefore the form of the section $C'D'$ would be exactly the same as that of the upper part of $A'B'$. As the

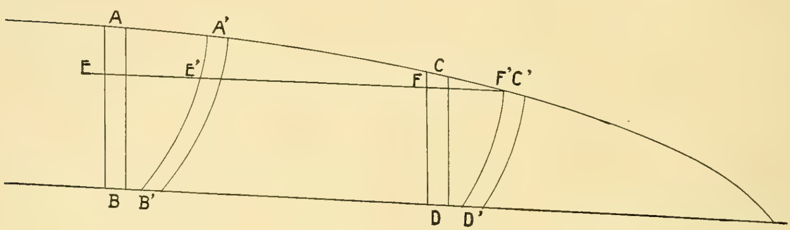


FIG. 1. Displacement of sections by flow.

slope of $E'B'$ is greater than that of $F'B'$, it is evident that more ice would enter through EB than would leave through FD in the same time, EF' being parallel to the bed of the glacier; but this is impossible under the supposition of normal flow, for we have only considered a part of the glacier below the surface, where no melting takes place.[1] The tendency of the thicker sections to move faster than the thinner ones, at the same distance from the bed, causes a forward pressure on the latter, increasing their velocity, and a backward pressure on the former, diminishing their velocity. The ice near the lower end of the glacier is thus under a pressure greater than the *normal pressure*[2]

number of pieces of ice on a slightly inclined rough sandstone slab, and found that the mass slowly slid down the slope with a uniform velocity approximately propo1tional to the pressure against the slab and to the angle of inclination, for angles between 1° and 10°. When the sandstone was smoothed but not polished a motion was observed at an inclination of forty minutes. The ordinary laws of the friction between solid bodies do not apply at all to the forces between a glacier and its bed.

[1] We here neglect the melting at the lower surface of the glacier which is so small as not to alter the argument.

[2] The normal pressure is the pressure which would exist if the glacier were of infinite length and uniform section.

and would therefore have a tendency to rise, would be squeezed up, so to speak.

We cannot reason very definitely about the pressure above the névé-line, for the much increased breadth of the reservoir, the smaller density of the ice and the possibly greater slope of the bed may result in either pressure or tension according to their relations to each other and to the thickness of the glacier.

The idea of a pressure on the lower reaches of a glacier due to the ice above has been generally held by glacialists, but I think without satisfactory reasons. It seems to have been inferred generally from the diminishing velocity of the lower parts of the glacier; but it is not due to this, for it is quite conceivable that by an increasing slope, and suitable melting, every section might have its normal velocity; there would be no effective pressure upon the upper regions, and there might still be a diminishing surface velocity.

Indeed, the extra pressure is not due simply to diminishing flow, but to the fact that the flow diminishes more rapidly than the cross-section. This may be stated in algebraic language by saying that the normal flow is not proportional to the linear dimensions of the section; it is not even proportional to the square of the linear dimensions, but probably to the third power.

In the dissipator of a circular ice-sheet, or of a spreading glacier, successive sections increase in breadth with a more rapid diminution of thickness than in the case of a linear glacier. This causes a considerable pressure of the rear on the forward sections, resulting in a more rapid radial movement of the ice than would occur without this pressure and in the opening of radial crevasses. It is not unlikely that such crevasses determined the positions of the eskers formed during the glacial epoch.

Direction of flow — Stratification.— In order that the general volume of the glacier should be preserved we must have below the névé-line, where there is melting, a component of the motion towards the surface, and this component is strongest where the melting is greatest, *i. e.*, it gets larger as we descend the dissipator. On account of the gradual thinning of the glacier this

condition would be satisfied if the motion were everywhere parallel to the glacier's bed, but we have already seen that on account of the pressure from behind there is really a small movement of the ice away from the bed. Above the névé-line this is reversed. Here there is accumulation ; and, unless the reservoir continually increases in thickness, the motion must have a component downward into the glacier, and this component must be greater where the accumulation is greater, *i. e.*, in general as we ascend the reservoir. We can thus draw on the surface of the glacier the approximate directions of motion, and beginning at the névé-line, where, as there is neither melting nor accumulation, the motion must be parallel to the surface, we can connect these lines and have a diagram of the lines of flow in the whole body of the glacier (Fig. 2). The slight melting of the glacier in contact with its bed would produce a small component of the motion towards the bottom, and in the dissipator also towards the sides ; but in the reservoir the accumulation results in a movement away from the sides. In picturing to ourselves the relative velocities of points at different distances from the surface, it is best to consider points lying in a section drawn everywhere at right angles to the lines of flow. The velocity of points in such a section will diminish as we approach the glacier's bed, on account of the friction which acts on the ice there. We can also show the positions assumed by the strata of annual accumulations. Perhaps the best way to do this is to follow the successive positions of a chosen stratum. At the end of the summer the snow deposited during the previous year will end in a thin wedge at the névé-line, and its thickness will at every point equal the corresponding annual accumulation. A year later the end of this stratum, with but small loss by melting, will have been carried a short distance down the surface of the glacier ; and every point of the stratum following its proper line of flow, will have progressed down the valley and into the body of the glacier, and the stratum will have reached the position *2*. Continuing in the same way we can trace in a general way the position the stratum will have

in successive years; and these positions, at any one time, will correspond to those of successive annual strata.[1]

We readily see that the strata have a gentler slope than the lines of flow in the reservoir, but a steeper slope in the dissipa-

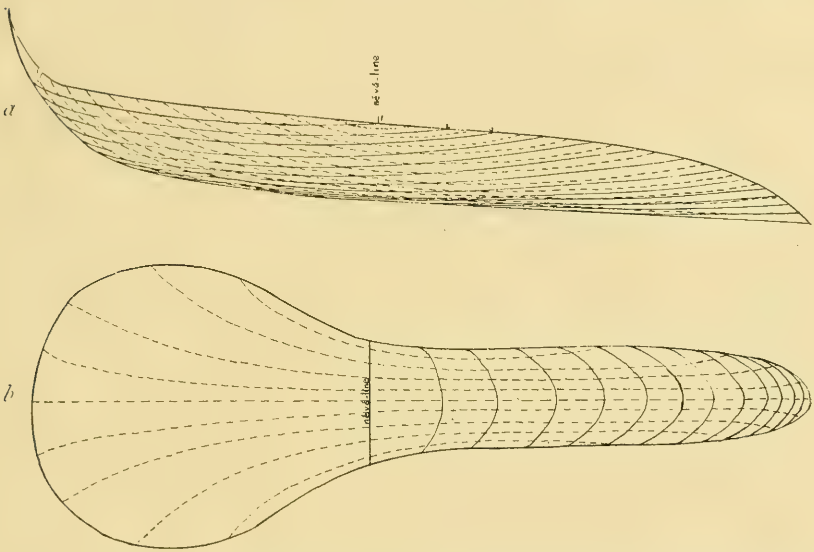


FIG. 2. Diagram of stratification (*a*), and lines of flow (*b*). Section and ground-plan.

tor; and that outcrops of strata can only occur below the névé-line.

The lower end of a new stratum is in the part of the glacier where the horizontal motion is greatest, and it never sinks far into the body of the dissipator, whereas, the upper end of the stratum originates in a region of small horizontal motion and later forms the lower layers of the glacier; the stratum, therefore, is stretched out and grows thinner on account of the differential motion, and also on account of the compression of the

[1] AGASSIZ (Syst. Glac., pp. 273–276) very nearly reached this conception of the disposition of strata and the direction of flow. Reverend O. FISHER (Phil. Mag., London, 1879, Vol. VII, pp. 381–393) presents somewhat similar ideas in connection with the stratification of Antartic ice. The theory presented above was developed before I was familiar with the latter's work.

snow into ice. During the first part of its course the angle which it makes with the bed of the glacier steadily increases; but later diminishes until probably it at last becomes nearly parallel with the glacier's bed.

It is to be noticed that the largest accumulation occurs under the mountain cliffs where the glacier receives, in the form of avalanches, much of the snow that falls on the slopes above. It is here then that the vertical component of motion is greatest, and it is also in this neighborhood that we find the *bergschrund;* which marks the line where the more rapidly moving ice below pulls away from the more slowly moving ice above. Reverend Coutts Trotter[1] has made the important suggestion that the *bergschrund* may mark the line above which the mean annual temperature is below freezing, and therefore the ice above it is frozen to the mountain, whereas, the ice below slides on its bed in addition to its shearing motion. Unfortunately, there is, so far as I know, no experimental evidence bearing on this point. Without disputing Mr. Trotter's idea, we see that the general theory leads us to expect a considerable change in motion in this part of the glacier; and when we recall that the surface slope diminishes rapidly below the *bergschrund*, we are driven to infer a rapid increase in the thickness of the glacier, and at least a large factor in the formation of the *bergschrund* becomes clear; for above it there is a thin coating of ice on the mountain slope, and below a much thicker mass of ice resting on an almost equally steep bed; and this would certainly result in a marked difference in velocity of the two parts.

Accurate observations on the direction of motion and on the stratification are few. Désor found at the side of the Unteraar glacier a motion of the ice having components down the valley, towards the side, and upwards.[2] Agassiz found by a line of stakes across the same glacier, whose positions and levels had been carefully determined, that during the winter the ice near

[1] Proc. Roy. Soc., 1885, Vol. XXXVIII, pp. 92–108. In this article Mr. Trotter describes some very instructive experiments showing that glacier ice will shear under very small forces if sufficient time is allowed.

[2] AGASSIZ, Système Glaciare, pp. 499–504.

the center of the glacier had suffered an upward displacement of 2.25 meters, and that the average upward displacement of the whole section was 1.4 meters.[1] These amounts are given after allowing for the natural thickening of the ice due to winter progression parallel to the glacier's bed, without melting. There is no apparent reason why the directions of flow in the winter and in the summer should differ; so I think these observations indicate a continuous movement of the ice toward the surface, as we should expect.

Professor Pfaff found in one of the reservoirs of the Aletsch glacier, where the surface slope was 9°, that the direction of motion made an angle of about 40° with the horizontal. This is certainly a high angle and Professor Heim does not think the method used sufficiently free of error to establish these "somewhat astonishing results."[2] Here again, however, the observations are in harmony with theory. It is unfortunate that so little has been done to determine the vertical component of the motion.

The correct observation of stratification is very difficult. It is next to impossible to determine the surfaces of separation of successive strata in the dissipator unless we find them marked by a thin layer of débris. Aggassiz has made a drawing of several such débris layers as they were exposed in a hole in the upper part of the dissipator of the Unteraar glacier.[3] These must be true surfaces of stratification; they dip up stream at an angle of about 30°.

Professor Russell has described débris layers in the Sierra Nevada glaciers, and suggests that they separate successive strata; they occur at fairly regular intervals, dip into the glaciers, and were only seen below the névé-line.[4]

When the junction of two glaciers, which gives rise to a

[1] Syst. Glac., pp. 559–563.

[2] HEIM, Gletscherkunde, p. 184.

[3] Syst. Glac., p. 260. Atlas Pl. V, Fig. 15.

[4] The Glaciers of the United States. 5th An. Rep. U. S. Geol. Surv., 1883–4, pp. 316, 319. Pl. XXXVII shows the outcrops of the layers in the Mt. Dana glacier. See also HEIM, Gletscherkunde, p. 131.

medial moraine, occurs in the dissipator, the moraine remains on the surface of the ice; but if the junction occurs in the reservoir the moraine is covered up by later strata of snow and reappears lower down in the dissipator; the further the junction is above the névé-line, the further is the point of reappearance of the moraine below that line. Rock material that falls on the snow from the cliffs in the cirque is carried by the flow along the under part of the glacier and reappears at the surface only near the lower end of the dissipator.

We have but few observations bearing on these theoretical inferences. In Agassiz's map of the Unteraar glacier one or two small moraines are shown as beginning on the surface of the ice some distance below the névé-line. And it is not at all unlikely that what is usually called the spreading of the moraines near the glacier's end is largely due to the appearance at the surface of the débris fallen on the glacier from the cliffs surrounding the reservoir. A glance at the lines of flow (Fig. 2) will make this clear.

The Gorner, the Findelen and the Zmutt glaciers, near Zermatt, end within a few miles of each other; the first two, originating on high snow-covered land surrounded by snow ridges, have a large portion of their surfaces comparatively clean to the end; the last, whose reservoirs are dominated by precipices from which rocks are continually falling, is entirely concealed at its lower end by débris. Of the tributaries of the Muir glacier in Alaska, Dirt glacier, originating in a cirque, has two or three miles of its lower end deeply covered by débris, whereas the White glacier, nearby, whose reservoir is not surrounded by cliffs, has ordinary linear moraines.[1]

The lines of flow (Fig. 2) explain why all observers have had practically unsurmountable difficulties in following the stratification from the reservoir through the dissipator.

The parts of the strata formed at a distance from rocky slopes have very little dust blown upon them, and consequently when they reappear at the surface in the upper or middle regions

[1] See Map in Studies of Muir glacier, Alaska, Nat. Geog. Mag., Vol. IV, p. 52.

of the dissipator the stratification is but slightly, if at all, indicated by dust bands. The strata should be well defined at the lower end, but the large amount of débris on the surface and in the crevasses, would make them difficult to recognize.

The débris in the lower layers of some glaciers may have a similar origin, and may not have been picked up from the ground beneath. Indeed, in general a downward rather than an upward motion probably occurs near the bottom, and some of the material forming the ground-moraine may have been originally dust or rock fallen on that part of the reservoir's surface, near the encircling cliffs, which afterwards formed the lower layers of the glacier. For, on account of the heat derived from the earth, two feet of ice would be melted from the glacier's under surface in a hundred years, and would deposit its débris under the ice.

Form of the glacier's surface.—For equilibrium the melting of the ice at every point of the surface must exactly equal the supply; this is the necessary condition; and since the upper layers move fastest, their melting must be fastest; this is brought about by the slope of the surface being least where the motion is most rapid, thus exposing to melting a larger surface of the layer. Or we may say that the angle between the direction of motion and the surface is greatest where the motion is smallest and the melting most active. At the end of the glacier, therefore, and near the ground, we find the slope steepest; and as we pass up along the surface of the ice the motion becomes faster and the melting less and consequently the slope diminishes. This also explains the rounded plan of the glacier's end and the depressed sides. If we knew accurately the distribution of velocity and of melting we could calculate the shape of the surface for equilibrium; but without this our approximate knowledge of these quantities enables us to see that the general form of the dissipator's surface agrees with the theory.

Glaciers are continually changing in size, so that the conditions for equilibrium can be looked upon as approximately

true only when the changes are small, or when an average is taken over a long period.

Form of the glacier's lower end.—Let us now give our attention to the lower end of the dissipator. We have seen that the surface slope at any point depends on the velocity and rate of melting at that point, and varies inversely with them. The general form will, therefore, depend on the differential velocity. (We are considering a portion of the glacier so small that we may suppose the melting uniform; though this would be somewhat modified by the direction of the sun's rays.) The larger the glacier, the greater in general will be the differential motion, and the more rapidly will the slope diminish as we ascend from the end. For very small glaciers the differential motion is small and the slope remains steep. If anything should cause an abnormally rapid melting of the lower layers, the natural slope could not be retained, but the upper layers would advance over the lower ones, project and break off. Professor Chamberlin[1] in his excellent descriptions and illustrations of the glaciers of northern Greenland has introduced us to just such forms. Fig. 3 is a section taken from one of Professor Chamberlin's photographs of Bryant glacier,[2] which is a good example of the type of glacier we are now considering. It is about 140 feet thick at the end; the lower layers, for something more than half its thickness, are full of débris; the upper ones are practically clear with an occasional layer of débris. The terminus of the glacier inclines slightly forward in the dirty lower layers, above which the clear ice projects in one or two somewhat overhanging vertical steps to the upper surface of the glacier, which slopes back from this point according to the natural surface of an alpine glacier. Wherever a débris layer occurs in the clear ice there is a reëntrant groove in the cliff, and the layer above overhangs. Wherever the layer of débris is interrupted so is the groove.

All indications show a very slow motion, which is probably entirely accounted for by the small thickness of the ice.

[1] This JOURNAL, Vols. II and III; Bull. Geol. Soc. Amer., 1895, Vol. VI, 199–220.

[2] Bull. Geol. Soc. Amer., 1895, Vol. VI, Pl. III, Fig. 2.

Professor Chamberlin has suggested that a partial cause of the vertical and overhanging ends is the greater effect of the nearly horizontal rays of the sun on the steep edges than on the sloping backs of the glaciers; this is undoubtedly a true cause; he thinks, however, it is not the whole explanation, but that there must be some special shearing at the débris-bearing layers.

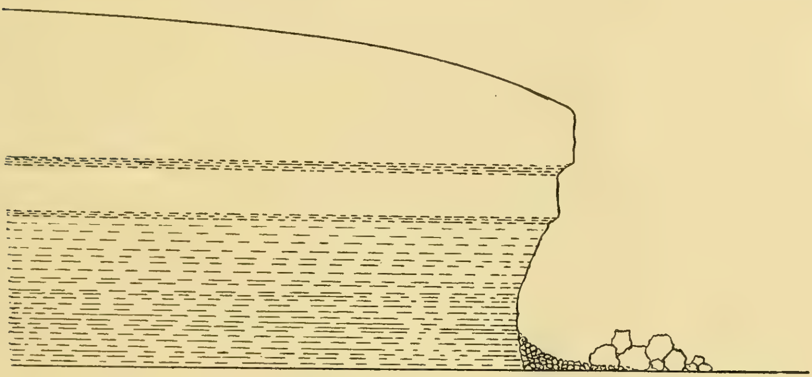


FIG. 3. Diagrammatic section of end of Bryant glacier.

This seems to me unnecessary; and Professor Russell[1] has lately made clear that the presence of débris in a glacier diminishes, instead of increasing, its power to shear.

The endings of these glaciers present a close analogy to the endings of tide-water glaciers. The lower layers of the latter have their extent determined by the equality between the rate of motion and the melting due to the salt water, and the upper layers project over them until they break off.[2] In these Greenland glaciers the extent of the lower layers depend on their rates of motion and of melting, and the upper layers push over them until they break off from lack of support, as is shown in the illustration referred to by the pieces of ice lying in front of the glacier. Above the vertical cliffs, thus produced, the ordinary conditions of melting prevail, and the surface of the glacier

[1] This JOURNAL, Vol. III, 823–832. The proof depends on the quasi-viscous theory of glacial movement.

[2] Studies of Muir glacier, Nat. Geog. Mag., IV, 47.

follows the ordinary alpine form. The débris is, however, an important factor in increasing the melting of the lower layers. It acts in two ways: it absorbs the sun's rays more abundantly than the ice does, and its presence reduces the effective density of the ice, so far as melting is concerned, just as air bubbles would. Its existence seems almost necessary for the development of overhanging ends, for there are glaciers in the same region which end like ordinary alpine glaciers;[1] and Professor Salisbury tells me that, so far as his observation went, all those, and only those, containing much débris in their lower layers, have vertical or overhanging ends well developed. Professor Chamberlin does not think this is universal.

Both of these endings are forms of stable equilibrium; for an increase of velocity, accompanied, as it must be, with an increase of differential velocity, would cause the upper layers to project more, resulting in more breakage; and the surface slope of the lower layers would overhang more, thus presenting a larger surface to the salt water or to the air, as the case may be, and increasing the melting; for we must remember that even in northern Greenland some of the melting comes from contact with the air, which, during the summer, is well above the freezing point.

Variations of glaciers.—Although the sloping surface of alpine glaciers is a surface of equilibrium, it is unstable, and any cause, such as a few years of greater melting or accumulation, which would alter this slope, would destroy the equilibrium, and the surface would tend to depart more and more from its equilibrium form. When the equilibrium of the surface is destroyed by diminished melting or increased flow, the upper layers everywhere advance over the under ones; of course, the higher and more rapidly moving layers advance at a greater rate, but as they are near the névé-line, where the direction of motion makes but a small angle with the glacier's surface, they cause but a very small swelling; nearer the end, however, the direction of motion,

[1] CHAMBERLIN, Bull. Geol. Soc. Amer., 1895, VI, 202. SALISBURY, this JOURNAL, 1895, III, 887–890.

making a higher angle with the surface, tends more directly to increase the thickness. This increases the velocity, causing a further departure from the equilibrium surface, and the glacier grows in length with a small increase of thickness in the reservoir, and with a great increase of thickness at its lower end. The ice is rapidly carried off until the upper part of the dissipator becoming thinner, there is a gradual diminution in velocity, and the end of the dissipator having advanced to warmer regions the melting is faster and the glacier begins to recede. This makes it evident that under certain conditions, such as a bed of increasing slope, a glacier, when once the equilibrium between its flow and melting is destroyed, might advance with strides entirely out of proportion to its usual motion, as has frequently happened with the Vernagt glacier.

A glacier having the equilibrium form corresponding to the climatic conditions prevailing at the time, would lose this form and respond immediately, by a change in length, to the slightest climatic change; whereas, a glacier widely removed from its equilibrium form could not respond by a change in length until the effects of the climatic change had accumulated sufficiently to bring the glacier back to, and carry it beyond, its equilibrium form. Two glaciers, in general similar, but differing in their exposure or slope, might be very differently removed from their respective equilibrium forms, and would therefore respond at different times to a given climatic change; indeed, one of them might be so far removed from its equilibrium form that a climatic change lasting for several years might not be long enough to reverse the condition of retreat or advance in which it happened to be.

Smaller glaciers in general respond more quickly to climatic variations, and we can see why this should be true; for, a change in the amount of snow-fall or of melting, would produce the same change in the actual thickness of two glaciers of different sizes, but subject otherwise to the same conditions. The smaller glacier would, however, experience a greater relative change in thickness, resulting in a greater relative change in flow; it

would therefore respond more quickly than the larger glacier; this is confirmed by observation. We should also expect a relatively greater change in size of its dissipator; although, from lack of data, I cannot say that this inference is borne out, still we know that many small glaciers entirely disappear after a few dry hot seasons, and reappear after a few cold wet ones.

This theory offers a connecting link between the theories of Professor Forel and Professor Richter.[1] According to it a glacier will respond to any climatic change, not by the progression of a wave along its surface, but by a change over the whole surface; but this change will not show itself by reversing the phase (the condition of advance or retreat) of the glacier until it has sufficiently accumulated to carry the surface up to and beyond its equilibrium form.

HARRY FIELDING REID.

[1] See this JOURNAL III, 278–288.

LOESS IN THE WISCONSIN DRIFT FORMATION.

Loess has long been known to cover the glacial drift of the earlier ice epochs at various points, especially along the water courses of the western portion of the Mississippi basin, and to have more or less extensive development in like relation to valleys in extra-glacial territory both west and south of the drift. It also occurs, especially along the Mississippi and its tributaries, in the driftless area which lies in Wisconsin, Illinois, Iowa, and Minnesota.

In addition to its occurrence at the surface over the older drift sheets, loess is known to occur between beds of till outside the area covered by the ice of the Wisconsin epoch. In some places the surface of this buried loess is marked by a soil, often of considerable thickness. These facts show that there are at least two sheets of loess connected with the earlier sheets of drift. The sheet of loess which overlies the Iowan drift often terminates abruptly, as a surface mantle, at the edge of the Wisconsin formation, but frequently passes beneath it. Outside the drift-covered country also there are, in some places, two distinct beds of loess, the one above the other.[1] The surface of the lower is often marked by a well-developed soil, and furthermore shows, by its color and chemical condition, that it was long exposed before the overlying mantle was deposited upon it.

The stratigraphical relations of the loess and drift, especially when taken in connection with other considerations, seem to point clearly to the conclusion that the loess had an intimate connection with the drift in origin, and that there were at least two epochs of loess deposition later than the first, and earlier than the last, glacial epoch. The uppermost bed of extra-glacial loess, where two are developed, seems to be capable of definite

[1] Geological Survey of Arkansas, Ann. Rep. 1889, Vol. II, p. 233.

correlation with that which overlies much of the drift of the Kansan and Iowan epochs, while the lower is presumably the equivalent of some or all the loess beneath the Iowan and above the Kansan drift.

Heretofore loess has not been known to occur in or above the drift of the Wisconsin epoch; but during the past summer it has been found in connection with this formation at several points in Wisconsin, namely, near Green Lake, Devils Lake, and Ablemans.

Loess near Green Lake.—Loess occurs in at least two localities near Green Lake, in Green Lake county. One of these points is about two miles northeast of the village of Dartford in the S. W. ¼ of Sec. 10 (Tp. 16, R. 13 E.), where the loess is worked as molding sand for brass foundries. The loess here was not seen to contain shells or concretions, and is calcareous only at its base, and there but slightly. Its texture is fairly normal. It is exposed to the depth of eight or ten feet. The loess at this point is between 150 and 200 feet above Green Lake, and near the crest of one of the many high ridges of the region, the summits of which represent an old base plain. Its substratum is till of the Wisconsin formation.

The other point where loess is found is at the west end of the lake in Sec. 4 (Tp. 15, R. 12 E.). The loess here is at a lower level, and on a slope which faces the lake. As in the other case, it overlies the drift of the Wisconsin formation. The loess at this second locality is of greater thickness than at the first, and is normal in texture, color, structure, and composition. It is calcareous, and has the roughly columnar structure which frequently characterizes loess exposed in vertical faces, and contains both the common types of gastropod shells, and calcareous concretions, though neither is plentiful. Its character is in every way such as to allow of no doubt of its being normal loess. Near its base it is interstratified with gravel.

The loess in the vicinity of Green Lake is of special interest, not only because of its association with the deposits of the last

glacial epoch, but also because its relations show, in at least one of the two localities, that it is not the work of wind.

Super-till loam about Green Lake.—All about Green Lake it is a striking fact that the till, and indeed the drift in general, is covered by a layer of loam two to five feet thick, which is sufficiently different from the underlying drift to attract attention. It varies from a moderately stiff clay on the one hand, to a rather sandy loam on the other. It is generally heavier than its substratum, though influenced to some extent by it. Where it overlies stratified drift, it is on the whole less clayey than where it overlies till. It is sometimes altogether free from stony material, though this is not the rule. The absence of stony material is more likely to be the fact where the loam is thick than where it is thin, and where it overlies stratified drift, than where it overlies unstratified. The stony content of the loam may be either coarse or fine. If it contain bowlders, as it sometimes does, they are in all cases, so far as seen, of a somewhat distant origin. Among the drift bowlders of the region diabase predominates, and every bowlder seen in the loam was of this type. The bowlders of the loam do not differ in shape from the bowlders of the same sort in the body of the drift. On the other hand, where the loam contains small stones they are in almost all cases of chert such as might have come from the local rock, especially the Lower Magnesian limestone; but in small bits it is not always possible to distinguish Lower Magnesian limestone chert from chert of other formations. The cherts are almost uniformly sharply angular. The stony matter both of the bowlder type and of the smaller pieces is more likely to occur at or near the base of the loam, than at or near its top. Occasionally there is an aggregation of small stones at the junction of the till and loam. So well developed and so persistent is this loam that the surface of whole fields and even farms is without a trace of bowlders, even where the till is notably bowldery.

There seems to be no special rule concerning the topographic distribution of the loam, further than that it is generally most

apparent on approximately level surfaces, and that it is least likely to be present on steep slopes. In general it does not appear to be stratified, though where it is thick it is occasionally marked more or less distinctly, with dark and light bands in an essentially horizontal position. This variation in color is probably the result of chemical changes since its deposition, brought about by the concentration of coloring matter along definite horizontal lines. The concentration along these definite plains probably means some variation in texture along these plains, and this probably points to stratification.

As seen in section, the contact of the loam above with the till below is usually irregular, but often sharply marked. Both the regularity and the distinctness of the contact are more striking between the loam and stratified drift than between the loam and till.

Where the loam overlying till attains a thickness of as much as four or five feet the lower portion very commonly approaches loess in character. Where the loam is thin, say two or three feet thick only, it does not resemble loess, though it is not unlike the uppermost two or three feet of clay-loam which overlies loess in regions where the latter has its more clayey and less normal development.

The suggestion of connection between the loam and loess was given added force by finding loess at the two points mentioned, in just such situations and relations as that in which the loam commonly occurs.

Loess at Devils Lake.—East of the south end of Devils Lake fresh railway cuts reveal the presence of loess on the terminal moraine of the Wisconsin epoch. The crest of the moraine along the line of the railway at this point is, according to the topographic map, between 60 and 80 feet above the lake. The loess may be seen on both the inner and outer slopes of the moraine, but does not cover its summit, failing to reach it on either side by about ten feet.

While some of the loess here is thoroughly typical, it locally grades, either horizontally or vertically, into clay which is very

unlike loess. It is sometimes capped by several feet of heavy clay, which is clearly not the product of loam-weathering. Calcareous concretions occur but rarely, as also those of iron oxide. Shells were not seen. The loess, and especially the associated and genetically equivalent clay, contains an occasional stone of considerable size. The loess, and the clay which goes with it, have a maximum thickness of not less than fifteen feet.

There seems to be adequate reason for believing that the loess on the outside of the moraine (toward the lake), was accumulated in the expanded lake which occupied the site of the present lake and its surroundings at the time of ice occupancy. There is independent evidence that the lake stood at least sixty-five feet above its present level. This evidence is found in the presence of what appear to be berg-floated bowlders, up to this height about the borders of the depression (then a bay) at the southwest corner of the lake.

The loess on the inner slope of the moraine doubtless settled out of water which stood there after the ice had withdrawn a short distance to the east.

Loess at Ablemans.—Ablemans is about eight miles west of the moraine of the Wisconsin epoch, and in an area not overspread by the ice of any earlier epoch. Here at the extensive sandstone quarries, there is a fine exposure of loess not less than twenty feet in thickness. It occurs at a rather low altitude, and in such topographic relations as to bring it into unmistakable connection with the broad lacustrine (now terrace) flat which occupies the valley of the Baraboo, from Baraboo to Ablemans. The exposure is in a ravine, tributary to the Baraboo, and but a few rods from it. The lacustrine flat with which this loess is to be correlated is generally made up, superficially at least, of laminated calcareous clay, very unlike loess. It is to be especially noted that the loess at Ablemans does not occur next the moraine, but eight miles away in a small tributary ravine, the head of which did not receive glacial drainage, and that much finer deposits (clay) occur in the main valley between the loess and the moraine where the water was discharged from the ice

to the lake. The loess is here rich in calcareous concretions, and in gastropod shells of the types which abound in the loess. It also posesses the normal loess texture and structure. Indeed much of it is not wanting in a single distinctive loess characteristic. Bones of small mammals, as yet unidentified, were found at this point, at least ten feet below the top of the loess, and in such relations as to make it certain that the loess had not been disturbed or the bones introduced since the deposition of the formation. The loess here lies against a steep slope of sandstone and quartzite, and occasionally contains fragments of each.

A few rods away, at the same, or approximately the same level, an exposure in an isolated remnant of the terrace shows it to be made up of sand interbedded with loam which approaches loess in texture. The sand and loam are distinctly stratified and the stratification appears to be the work of water. The sand and loam at this exposure do not lie against a rock slope and no stones or pebbles were found in it.

The occurrence of loess at Ablemans is of special interest because it connects itself with the deposits of the lake which formerly occupied the valley of the Baraboo above the city of the same name. The lake was called into existence because the ice blocked the eastward drainage of the valley. It was maintained for a short time after the ice retired by the moraine dam which it left just above the City of Baraboo, Its position in a ravine through which glacial drainage did not flow, is also of significance.

The loess at Devil's Lake and at Ablemans, like that in the vicinity of Green Lake, was certainly deposited by water, and by water associated with the ice of the last glacial epoch. With the loess of Ablemans is to be correlated the clay in the valley of the Baraboo exposed at various points above the city, and the loams and clays, some of which are very loess-like, in the valleys of Seeley's and Narrow's creeks south of the Baraboo. The loam at Logansville in one of these valleys was seen many years ago to contain shells, and to be in other ways, somewhat loess-

like. At this point (Logansville) it is distinctly stratified, in places at least, and constitutes, or at any rate covers, the valley flat.

Loess-like loam about Baraboo.—In addition to the distinct development of loess at Devil's Lake, the surface of the drift about Baraboo is often marked by loam no less distinct than that about Green Lake. The surface loam does not seem to be restricted to the surface of the drift, but affects the extra-glacial surface as well. Even the high quartzite ridges seem to have a capping of it, though it cannot be affirmed that the loam (or clay) on these ridges is the equivalent of that over the drift.

The "east bluff" (the quartzite bluff east of the lake), 1560 feet above the sea level, and 800 feet above the valley of the Wisconsin five miles to the south, has a goodly development of clay-loam (five or six feet) upon it. This is exposed in but few places, but the sturdy character of the forest shows that there must be some soil other than that which could have arisen from the decomposition of the quartzite. At the spot where the problematical gravel heretofore described occurs[1] the gravel overlying the quartzite is covered by five to six feet of nearly stoneless clay loam. Its aspect is such as to suggest its genetic connection with the loess. This loam, or something very like it, whatever its origin, is widespread. Whatever is true of the extra-glacial surface loams, that which overlies the drift about Baraboo seems to belong with that which overlies the drift at Green Lake, and which so frequently grades toward normal loess and sometimes assumes the character typical of that formation. I now believe it to be the equivalent of the stoneless, or well nigh stoneless, mantle of clay which occurs at some points about Madison, and which I was formerly inclined to regard as wind-blown dust accumulated on the ice and deposited in the final melting.[2] In the adequacy of this suggestion I

[1] JOUR. OF GEOL., Vol. III, p. 655.

[2] Proc. Am. Ass. for Adv. of Sci. 1893, p. 180. See also Ann. Report of the State Geologist of N. J., 1893, pp. 211–24.

have less confidence than formerly. The phenomenon to be explained is widespread and may involve a much bolder hypothesis.

Loess-like loam near Camp Douglas, Wis.— In the vicinity of Camp Douglas, Wis., there is a considerable development of loess-like loam which is probably genetically connected with loess, though lithologically not identical with the normal phase of that formation. Nevertheless it frequently approaches loess very closely in physical character.

Like Ablemans, Camp Douglas is outside the glaciated area. The station itself is about twenty miles west of the Wisconsin River, on a base-level plain of somewhat extensive development. About the Camp the general plain is marked by occasional notable elevations of sandstone rising up about 200 feet above the flat. To the west there is a dissected plain at a corresponding elevation. Above this plain, which represents a base-plain older than that already referred to, rise other elevations something like 200 feet higher. These are remnants of a base-plain developed during a still earlier cycle of erosion. The dissected plain which stands 200 feet or so above the railway at Camp Douglas is of sandstone, but it is mantled by a clay-loam, to which the sandstone could hardly have given rise. It is rarely exposed, but about four miles northwest of Camp Douglas a section may be seen which shows that, in its general features, it is very similar to loess; that, indeed, it is indistinguishable from some of the less normal phases of that formation. The exposure is at the head of a ravine cut into the upper plain referred to, and from its position and relations there can be no doubt of its continuity and genetic unity with the clay-loam mantle which overspreads the plain.

It is possible that the lowest plain about Camp Douglas was flooded by glacial water during the Wisconsin epoch of the glacial period. It is tolerably certain that the higher plain was not so covered. This loess-like loam is therefore believed to be connected, not with the Wisconsin formation, but with one of

the earlier epochs, though which one, it is, in the light of present knowledge, impossible to say.

Whether loess or anything genetically equivalent to it extends over the elevations which rise above the dissected plain has not yet been determined. The remnants of this earlier and higher plain, so far as visited, were limited in extent, and any loam which might once have covered them would be likely to have disappeared. It is to be borne in mind, however, that these elevations are lower than the Baraboo quartzite ranges, over which clay loam has been deposited in recent time.

There can be little doubt that loam, sometimes clayey (especially over limestone), and sometimes sandy (especially over sandstone), but in all probability genetically connected with the loess, is widespread in the driftless area.

ROLLIN D. SALISBURY.

GEOLOGY OF CHIAPAS, TABASCO AND THE PENINSULA OF YUCATAN.[1]

STRATIGRAPHY.

If one observes the general features of the distribution of the geological formations which constitute the states of Southeastern Mexico he soon finds that in the states of Chiapas and Tabasco there are various distinct geological zones; a very ancient one in the south of Chiapas formed of plutonic rocks and Palæozoic formations; another, more modern, in the middle and northern regions made up of Mesozoic and Tertiary formations. At the foot of each of the above mentioned zones Quaternary deposits are found, forming great plains slightly elevated above sea level. In the Peninsula of Yucatan there is not such a variety of geological formations. Nearly all that extensive region presents a uniform character, which shows that there have not been there so many geological disturbances as in the mountainous regions of Chiapas, and that these deposits were formed under different conditions. In treating of the orography I will speak more in detail of these differences. Yucatan is a part of the earth which has not participated in the dislocations and depressions that the sedimentary deposits, both Palæozoic as well as Cretaceous and Tertiary, of Chiapas have undergone, resulting in the development of mountain chains in that state. The strata are almost horizontal or a little inclined in Yucatan,

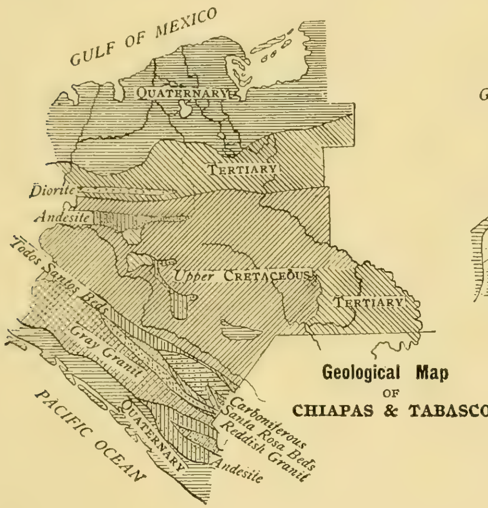
[1] Boletín del Instituto Geológico de México, Num. 3, La Geografia Fisica y la Geologia de la Peninsula de Yucatan, Mexico. 1896. Roy. 4°, 57 pp., 2 pl. of sections and 3 folded maps.

The work from which the following translation is taken is divided into five parts, viz., geology, orography, hydrography, climatology and distribution of the floral zones, and productions. Part I, geology, seems to us deserving of a wider circle of readers than it is liable to obtain in its original form, and hence we have prepared this translation. The accompanying photo-engravings are sketched from Sapper's geological maps, and will serve to indicate the general distribution of the different formations as understood by that authority.

while on the contrary those in Chiapas are generally much inclined and fractured.

A. SEDIMENTARY FORMATIONS.

1. *Azoic formations.*—In addition to some very limited bands of gneiss, mica-slate, and phyllites surrounded with granite, which I observed in 1893 in the Sierra Madre, in 1894 I came



across in the first northern range of the same Sierra, near the plantations of "Piedad" and "San Vicente," another band of crystallines trending N. 7° W. and dipping 5° to the N. E. Among bowlders washed down by the Aguacate River one can see gneiss, mica-slate, and phyllites, which indicate the presence of these formations in these regions and in the interior of the Sierra Madre.

On account of the total absence of means of communication in the Sierra mentioned, entrance to the interior, now practically unknown, is almost impossible; hence on the geological map I have not been able to indicate the occurrence of the Azoic formations except in a very general way.

2. *Strata of Santa Rosa.*—As I said in a preliminary report in 1893, I have adopted this term of the French geologists, A.

Dollfus and E. de Montserrat, to indicate a system of red arenaceous and slaty conglomerates which is beneath the Carboniferous limestones. I showed that the upper strata of this system in the neighboring Republic of Guatemala contain Carboniferous fossils, and although it is impossible to determine with exactness the age of the lower beds, probably they are Carboniferous or Devonian. The extent of the Santa Rosa beds is very considerable, since near Porvenir, in San Francisco Motozintla, there are important mountain chains formed almost exclusively of these beds.

These beds, like the Carboniferous limestones, are found only in the southeastern part of Chiapas. I was unable to ascertain exactly how far west they extend, but I think that they terminate at their contact with the granite rocks which form the nucleus of the Sierra Madre.

3. *Carboniferous limestone*.—The limestones and dolomites of the Carboniferous terranes have a moderate extension in the state of Chiapas, as is shown on the geological map. Their age is roughly ascertained by various fossils which I have found in the vicinity of La Nueva, Las Tres Cruces, and Palo Amarillo, which have not yet been determined (specifically).

I have also found Carboniferous fossils, as brachiopods, corals, and crinoids, near San Vicente, in the department of Comitan, in calcareous rocks, cemented together with silicon, probably in Tertiary times. At nearly all the points which I know the Carboniferous limestones lie conformably upon the Santa Rosa beds. In the vicinity of Chicomucelo and Palo Amarillo beds of limestone were seen intercalated between the slates and flagstones of the above-mentioned beds. In the preliminary report of 1894 and in the "Grundzuge der physicalischen Geographie von Guatemala" (Gotha, 1894), I have given the list of the Carboniferous fossils which up to the present date have been found in the Republic of Guatemala.

4. *Strata of Todos Santos*.—A system of sandy and slaty conglomerates of a red or reddish color, which I have termed for reasons before given the "strata of Todos Santos," are found

along the northern base of the Sierra Madre. The beds are a little inclined to the north in many places where I was able to ascertain the dip. They do not lie conformably over the Carboniferous limestones, and apparently their deposition occurred after the primary formation of the Sierra Madre, along the shores and bottom of a sea, later than the Carboniferous but before the Cretaceous, and that they have undergone few dislocations or alterations.

I cannot give any exact data on the relative age of these beds because I have found no fossils in them. Perhaps they are deposits of the Triassic period, the latter having been found in the Republics of Honduras [1] and Nicaragua.[2]

The formations 1 to 4 occur only in the southern part of Chiapas. The northern parts of the same state are made up of more recent sedimentary rocks, of the Cretaceous and Tertiary.

5. *Cretaceous limestone.*—In the greater part of the northern region of Chiapas are limestones and dolomites, both of the Cretaceous period. I have found *Rudistes*, *Radiolites sp.*, and *Spherulites sp.* between San Cristobal, Las Casas, and Teopisca, between Teopisca and San Lazaro, between San Bartolomé de los Llanos and San José de La Canoa, between Santa Isabel and Campana (Department of Comitán, near Comitan), between El Calvairo and Chiapa, between San Vicente and Soyaló, where I also met with some Nerineas, near to San Cristobal, Las Casas, and between Yochiu and Tenejapa. All these points are situated in the southern part of the Cretaceous belt.

In the northern portions of the same zone I could not find any traces of Rudistes, but I found remains of fossil corals in various places, as in La Puncta, the Catate and Salvador rivers, between Sabanilla and Tila, and between Tila and Tumbalá.

These organic remains have not been examined with sufficient care as yet to enable one to say whether the limestones containing the rudistes and those containing the corals belong

[1] Dr. R. Fritzgartner, Kaleidoscopic views of Honduras, in Honduras Mining Journal. 1891. Num. 6–8. Tegucigalpa.

[2] Dr. Bruno Micrisch, Eine Reise quer durch Nicaragua, in Petermann's Mitteilungen. Gotha, 1895. Pp. 57, et seq.

to different horizons of the Upper Cretaceous, or whether they are contemporaneous formations of different appearance.

I found a fossil fish in a very fine-grained limestone which resembles the lithographic stone of Solenhofen. The ancient Indians used this stone in the construction of Palenque.

In the strata which occur in the eastern part of Chiapas I have not obtained fossils either along the road from Tenosique to Real, or on the banks of the Usumacinta and Lacantún. Yet I think that they are Cretaceous because in the eastern continuation of the few sierras of Chiñiquijá, I have found in La Libertad, department of the Petén, a few badly preserved fossils which Geheimerat von Zittel, in Munich has examined and determined to be Cretaceous.

6. *Cretaceous Marls and Clays.*—Near Tuxtla Gutiérrez and Chiapa there are some deposits of marls and clays which contain fossils, as yet not well studied, of the genera *Heliopora*, *Leptophyllia*, *Goniastræa*, *Stylina*, *Cryptocœnia* and *Turritella*. They are of an Upper Cretaceous horizon and more modern than the Cretaceous limestones on which they lie. I do not remember meeting with these beds in any other part of the state. The strata of this formation are a little inclined, or sometimes horizontal, as in the valley of Tuxtla and Chiapa.

7. *Tertiary.*—The Tertiary is found in many parts of the northern and central regions of Chiapa and in the southern part of Tabasco. In Tabasco the Tertiary is for the most part covered over with thin Quaternary strata.

As I have said in the preliminary report of 1893, the majority of the Tertiary is composed of marls and clays, sands and conglomerates while the limestones are of less importance.

I repeat that I found in 1893 a species of *Pecten* near Zacualpa, *Ostreas*, *Nummulites*, *Clypeaster*, and different gastropods, lamellibranchs and corals near Sacramento, the Relcario, Testaquim and Istapa, belonging, as far as have been examined, some to the Upper Miocene and some to a lower horizon. In 1889 I found near San José, department of the Comitán, remains of plants and foraminifera which Mr. C. Schwager in Munich deter-

mined as Tertiary. In 1891 I found in the alluvium of the Chixoy River Tertiary species of *Ostrea* and *Cerithium*.

In 1894 I found Tertiary fossils near Moyos, Sabanilla, Tila and Tumbalá ; *Ostraæ* in Tenosique, near Chinajá, in San Antonio, department of La Libertad, Chiapas ; near Tenejapa and at other points. Other Tertiary fossils (Lamellibranchs) were found by D. Joaquín Zetina on the banks of the Lacanjá River, the Aguilar and other streams, and one *Ostrea* by D. Jose Tamborrel in the southern part of Tenosique.

I found in Real, department of Chilón, and in San Antonio, department of La Libertad, Chiapas, fossil plants in Tertiary terraines ; but as they were not in place, I could not determine their age.

The Tertiaries are generally very much inclined ; in the neighborhood of Istapa, of San Antonio, of Tenejapá and Tumbala, the strata are horizontal or of very gentle dip ; they are more modern than the andesitic eruptions because they enclose pebbles of the latter, as in Burrero, district of Istapa ; and in some cases the horizontal rocks lie directly above the andesite, as near to Tenejapa.

In the peninsula of Yucatan Tertiary beds predominate ; and it seems that from the south to the north the successive strata become more and more recent until the Post Pliocene and Quaternary of the north coast is reached. I think that the nearly horizontal or little inclined Tertiary beds of Yucatan which I have observed, have a general, gentle slope toward the north, and that a great part of the more recent Post Pliocene beds were submerged under the sea in comparatively recent times as Heilprin concludes was the case with the "Banco de Yucatan," and quite probably the submerging took place very slowly, just as now, according to my own observations, the Atlantic coast of Guatemala is slowly sinking.

The southern parts of Yucatan show calcareous formations often containing much silicous matter. Among the limy layers, too, are occasional beds of marl and others of gypsum (alabaster). In the mountain chain of Ixconconcal, near Icaiché, I

found a number of fossils which could be used for determining the age of these deposits. The gypsiferous layers have not been seen to the north of the vicinity of Haltum.

Certainly these southern deposits belong to a lower horizon than the northern deposits which were studied by Professor Angelo Heilprin. This noted geologist has distinguished the following horizons:

(*a*) Limestones, gray or white in color, which can well be studied in the cave of Calcehtok, the entrance of which is 200 English feet above sea level, Fossils are rare and the following only were found: *Pecten nucleus*, *Pecten* sp., *Marginella* (sp. cf. *labiata*), *Potamides*, or *Cerithides*, *Oliva*, *Venus cancellata*. Mr. Heilprin says that the age of this limestone is Miocene or Pliocene, and not Oligocene as has been held by Alexander Agassiz.[1]

(*b*) Limestones, red or reddish in color, lying above semi-crystalline marble or yellow limestones, very fine-grained, resembling the lithographic limestone of Solenhofen. Breccias of limestone occur at the foot of the hills. In the red limestone a *Helix* was found between Ticuli and Santa Elena, at an altitude of 300 feet above sea level, and another fossil which seemed to be a *Macroceramus*, in the cave of Calcehtok. Both these fossils are terrestrial, but it could not be said with certainty whether all the limestone is of terrestrial origin. The above limestones occur in the hilly parts of Yucatan. I notice that Mr. Heilprin does not mention the flint masses which are found in the same regions and which are used in the vicinity of Ticul for the manufacture of mill stones.

(*c*) The Pliocene limestone which predominates in the low regions of the north of Yucatán and which was examined by Mr. Heilprin, especially in Mérida, and between Mérida and Calkini, Mérida and Ticul, Mérida and Tunkás, and between Tekanto and Silam.

Professor Heilprin has found in it the following fossils:

Pecten nucleus,	Tekanto, Mérida, between Mérida and Ticul.
Pecten n. sp.,	"

[1] Three Cruises of the Blake, Vol. I, p. 69.

Anomia simplex, (?)	
A. Ruffini ?	
Plicatula filamentosa,	Tekanto.
Lucina reticulata,	"
Arca Adamsi	"
Venus mercenaria,	"
Venus cancellata,	Tekanto, Mérida, between Mérida and Ticul.
Marginella apicina,	"
* *Turritella peratenuata*,	"
* *Turritella apicalis*,	"
Bulla striata,	"
* *Amusium Mortoni*,	Izamal, Mérida.
Cardium isocardia,	Mérida.
Venus Listeri,	"
Pecten sp. ?	Between Mérida and Ticul.
Pinna sp. ?	" " "
Lucina Jamaicensis,	" " "
Lucina edentula,	" " "
Cardium Magnum ?	" " "
Cardium muricatum,	Mérida.
Murex Salleanus,	Between Mérida and Ticul.
* *Ostrea meridionalis*,	Mérida.
Arca Deshayesii,	"
* *Arca* sp.,	"
Arca rombea,	"
* *Pectunculus* sp.,	"
Lucina tigrina	"
* *Lucina disciformis*,	"
Lucina Pennsylvanica,	"
Cardium serratum.	
Chama arcinella,	"
Venus Mortoni,	"
Artemis discus,	"
Macoma contracta,	"
Tellina sp.,	"
* *Fulgur rapum*,	"
Dolium perdix,	"
Oliva literata,	"
Cypræa sp.,	"
Pyrula reticularis,	"
Siliquaria sp.	"

* Not living in neighboring seas.

All these fossils are of the Pliocene; the formation is equivalent to that of Florida. Corals are rare and have not contributed to any great degree to the formation of the rocks. The fossils which I found in Mérida have not as yet been determined.

8. Post-Pliocene or Quaternary limestone, only on the northern coast and in the isolated patches in the interior of the peninsular; the remainder of the formation in the interior has been destroyed by erosion. It is characterized by *Venus cancellata* and according to Heilprin, continues northward under the sea.

B. ERUPTIVE FORMATIONS.

9. *Granite.*—Granite forms the greater part of the Sierra Madre of Chiapas; one reddish variety occurs in the northern part of that mountain chain. This granite seems to be of a later age than the Carboniferous, because the mountain chains composed of the limestone of that terrane and of the Santa Rosa beds cease abruptly upon contact with the plutonic rocks of the Sierra Madre. I have been unable to study the conditions at these points on account of the total absence of roads.

10. *Diorite.*—Diorite occurs in the northwest part of Chiapas and forms by itself a few mountain chains; it appears to be of Tertiary Age.

11. *Serpentine.*— In the region of San Francisco Motozintla various dikes of serpentine of a limited area occur between Malpaso and San Isidoro and in the vicinity of Chimalapa.

12. *Andesite.*—Andesite eruptions have been found only in the State of Chiapas; in the northwest, andesitic hypersthene is found forming a mountain chain of considerable altitude (more than 2000 [meters?]), and in the central part of the state hornblendic andesite occurs forming the chains to the north and southwest of San Cristobal, Las Casas and the picturesque chains of Mispilla and San Bartolomé de los Llanos, besides many dikes of minor importance. These andesites made their eruptions successively during the Tertiary epoch and before the formation of the Neo-tertiaries of Burrero near Istapa and Tene-

japa, but probably after the dislocations of the beds of the Upper Miocene of Sacramento. In the Sierra Madre there were other great eruptions. I have been unable as yet to mark out the westward limit.

VOLCANOES.

The only volcano known in the state of Chiapas is Tacaná (3990 meters), through the apex of which passes the dividing line between the Republics of Mexico and Guatemala. Its latest eruption took place in 1855.

CARLOS SAPPER.

[Translated by C. Joaquina Maury and G. D. Harris.]

Studies for Students.

STRATIFIED DRIFT.

CONTENTS.

Its abundance.—The notion is widespread that the drift deposits of the glacial period are unstratified. Lack of stratification, indeed, is the characteristic which, above all others, is popularly supposed to be the special mark of the formations to which the ice gave rise.

While it is true that glacier ice does not distinctly stratify the deposits which it makes, it is still true that a very large part of the drift for which the ice of the glacial period was directly or

indirectly responsible is stratified. That this should be so is not strange when it is remembered that most of the ice was ultimately converted into running water, just as the glaciers of today are. The relatively small portion which disappeared by evaporation was probably more than counterbalanced, at least near the margin of the ice, by the rain which fell upon it. It cannot be considered an exaggeration, therefore, to say that the total amount of water which operated upon the drift, first and last, was hardly less than the total amount of the ice itself. The drift deposited by the marginal part of the ice was affected during its deposition, not only by the water which arose from the melting of the ice which did the depositing, but by much water which arose from the melting of the ice far back from the margin. The general mobility of the water, as contrasted with ice, allowed it to concentrate its activities along those lines which favored its motion, so that different portions of the drift were not affected equally by the water of the melting ice.

All in all it will be seen that the water must have been a very important factor in the deposition of the drift, especially near the margin of the ice. But the ice-sheet had a marginal belt throughout its whole history, and water must have been active and effective along this belt, not only during the decadence of the ice-sheet, but during its growth as well. It is further to be noted that any region of drift stood good chance of being operated upon by the water after the ice had departed from it, so that in regions over which topography directed drainage after the withdrawal of the ice, the water had the last chance at the drift, and modified it in such a way and to such an extent as circumstances permitted.

Its origin.—There are various ways in which stratified drift may arise in connection with glacier deposits. It may come into existence by the operation of water alone; or by the coöperation of ice and water. Where water alone was immediately responsible for the deposition of stratified drift, the water concerned may have owed its origin to the melting ice, or it may have existed independently of the ice in the form of lakes or

seas. When the source of the water was the melting ice, the water may have been running, when it was actively concerned in the deposition of stratified drift, or it may have been standing (glacial lakes and ponds) when it was passively concerned. When ice coöperated with water in the development of stratified drift the ice was generally a passive partner.

GLACIAL DRAINAGE.

The body of an ice-sheet during any glacial period is probably melting more or less at some horizons all the time and at all horizons some of the time. Most of the water which is produced at the surface during the summer sinks beneath it. Some of it may congeal before it sinks far, but much of it reaches the bottom of the ice without refreezing. It is probable that melting is much more nearly continuous in the body of a moving ice-sheet than at its surface, and that some of the water thus produced sinks to the bottom of the ice without refreezing. At the base of the ice, so long as it is in movement, there is doubtless more or less melting, due both to friction and to the heat received by conduction from the earth below. Thus in the ice and under the ice there must have been more or less water in motion throughout essentially all the history of an ice-sheet.

If it be safe to base conclusions on the phenomena of existing glaciers, it may be assumed that the waters beneath the ice, and to a less extent the waters in the ice, organized themselves to a greater or less degree into streams. For longer or shorter distances these streams flowed in the ice or beneath it. Ultimately they escaped from its edge. The subglacial streams doubtless flowed, in part, in the valleys which affected the land surface beneath the ice, but they were probably not all in such positions.

The courses of well-defined subglacial streams were tunnels. The bases of the tunnels were of rock or drift, while the sides and tops were of ice. It will be seen, therefore, that their courses need not have corresponded with the courses of the valleys beneath the ice. They may sometimes have followed lines

more or less independent of topography, much as water may be forced over elevations in closed tubes. It is not to be inferred, however, that the subglacial streams were altogether independent of the sub-ice topography. The tunnels in which the water ran probably had too many leaks to allow the water to be forced up over great elevations. This, at least, must have been the case where the ice was thin or affected by crevasses. Under such circumstances the topography of the land surface must have been the controlling element in determining the course of the subglacial drainage.

When the streams issued from beneath the ice the conditions of flow were more or less radically changed, and from their point of issue they followed the usual laws governing river flow. If the streams entered static water as they issued from the ice, and this was true where the ice edge reached the sea or a lake, the static water modified the results which the flowing waters would otherwise have produced.

STAGES IN THE HISTORY OF AN ICE-SHEET.

The history of an ice-sheet which no longer exists involves at least two distinct stages. These are (1) the period of growth, and (2) the period of decadence. If the latter does not begin as soon as the former is complete, an intervening stage, representing the period of maximum ice extension, must be recognized. In the case of the ice-sheets of the glacial period, each of these stages was probably more or less complex. The general period of growth of each ice-sheet is believed to have been marked by temporary, but by more or less extensive intervals of decadence, while during the general period of decadence, it is probable that the ice was subject to temporary, but to more or less extensive intervals of recrudescence. For the sake of simplicity, the effects of these oscillations of the edge of the ice will be neglected at the outset, and the work of the water accompanying the two or three principal stages of an ice-sheet's history will be studied

as if interruptions in the advance and in the retreat, respectively, had not occurred.

As they now exist, the deposits of stratified drift made at the edge of the ice or beyond it during the period of its maximum extension present the simplest and at the same time most sharply defined phenomena, and are therefore considered first.

DEPOSITS MADE BY EXTRAGLACIAL WATERS DURING THE MAXIMUM EXTENSION OF THE ICE.

The deposits made by the water at the time of the maximum extension of the ice and during its final retreat, were never disturbed by subsequent glacier action. So far as not destroyed by subsequent erosion, they still retain the form and structure which they had at the outset. Such drift deposits, because they lie at the surface, and because they are more or less distinct topographically as well as structurally, are better known than the stratified drift of other stages of an ice-sheet's history.

Of stratified drift made during the maximum extension of the ice, and during its final retreat, there are several types. Some of them have been adequately described and defined in the literature of glacial geology, and would need no more than passing reference in this connection, were it not that, under certain conditions, they lose their distinctive characteristics, without being altogether destroyed. Their recognition then becomes a matter of difficulty, and their real relations are likely to be misunderstood, when the phenomena are in reality rather simple.

A. At the edge of ice, on land.—If the subglacial streams flowed under "head," the pressure was relieved when they escaped from the ice. With this relief, there was diminution of velocity. With the diminution of velocity, deposition of load would be likely to take place. Since these changes would be likely to occur at the immediate edge of the ice, one class of stratified drift deposits would be made in this position, in immediate contact with the edge of the ice, and their form would be influenced by it. At the stationary margin of an ice-sheet, there-

fore, at the time of its maximum advance, ice and water must have coöperated to bring into existence considerable quantities of stratified drift.

The edge of the ice was probably ragged, as the ends of glaciers are today, and as the waters issued from beneath it, they must frequently have left considerable quantities of such débris as they were carrying, against its irregular margin, and in its reëntrant angles and marginal crevasses. When the ice against which this débris was first lodged melted, the marginal accumulations of gravel and sand often assumed the form of *kames*, a type of stratified drift which is well known.[1] A typical kame is a hill, hillock, or less commonly a short ridge of stratified drift; but several or many are often associated, giving rise to groups and areas of kames. Kames are often associated with terminal moraines, a relation which emphasizes the fact of their marginal origin.

So far as the superficial streams which flowed to the edge of the ice carried débris, this was subject to deposition as the streams descended from the ice. Such drift would tend to increase the body of marginal stratified drift from subglacial sources.

Marginal accumulations of stratified drift, made by the coöperation of running water and ice, must have had their most extensive development, other things being equal, where the margin of the ice was longest in one position, and where the streams were heavily loaded. The deposits made by water at the edge of the ice differ from those of the next class — made beyond the edge of the ice — in that they were influenced in their disposition and present topography, by the presence of ice.

[1] Until recently kames have not been discriminated from eskers, and in the older literature the two are confused. Kames, as distinct from eskers, are defined and discussed in the following places, though the list is incomplete:

CHAMBERLIN, 3d Ann. Rep. U. S. Geol. Surv., p. 300; Am. Jour. Sci., Vol. XXVII, p. 378; Compte-Rendu, 5th Session International Congress of Geologists, p. 187; JOURNAL OF GEOLOGY, Vol. I, p. 255; JOURNAL OF GEOLOGY, Vol. II, p. 531. GEIKIE, "Great Ice Age," 3d Edition, chap. xv. SALISBURY, Report of the State Geologist of New Jersey for 1891, pp. 89–95; Ibid., 1892, pp. 41, 79.

B. Beyond the edge of the ice, on land.—As the waters escaping from the ice flowed farther, deposits of stratified drift were made quite beyond the edge of the ice. The forms assumed by such deposits are various, and depended on various conditions. Where the waters issuing from the edge of the ice found themselves concentrated in valleys, and where they possessed sufficient load, and not too great velocity, they aggraded the valleys through which they flowed, developing fluvial plains of gravel and sand, which often extended far beyond the ice. Such fluvial plains of gravel and sand constitute the *valley trains*[1] which extend beyond the unstratified glacial drift in many of the valleys of the United States. They are found especially in the valleys leading out from the stouter terminal moraines of later glacial age. From these moraines, the more extensive valley trains take their origin, thus emphasizing the fact that they are deposits made by water beyond a stationary ice margin. Valley trains have all the characteristics of alluvial plains built by rapid waters carrying heavy loads of detritus. Now and then their surfaces present slight variations from planeness, but they are minor. Like all plains of similar origin they decline gradually, and with diminishing gradient, down stream. They are of coarser material near their sources, and of finer below. Such stratified drift, which constitutes a distinct topographic, as well as genetic type, is well known, and further description or discussion is unnecessary.

Where the subglacial streams did not course through subglacial valleys, they did not always find valleys at hand upon their issuance from the ice. Under such circumstances, each heavily loaded stream coming out from beneath the ice must have tended to develop a plain of stratified material near its point of issue—a sort of alluvial fan. Where several such streams came out from beneath the ice near each other for a considerable period of time, their several plains, or fans, were

[1] For fuller definition and illustration of valley trains see CHAMBERLIN, 3d Ann. Report U. S. Geol. Surv., p. 302; JOURNAL OF GEOLOGY, Vol. I, p. 534. SALISBURY, Report of the State Geologist of New Jersey, 1892, pp. 102–10r.

likely to become continuous by lateral growth. Such border plains of stratified drift differ from valley trains particularly (1) in being much less elongate in the direction of the drainage; (2) in being much more elongate parallel to the margin of the ice; and (3) in not being confined to valleys. Such plains stood an especially good chance of development where the edge of the ice remained constant for a considerable period of time, for it was under such conditions that the issuing waters had opportunity to do much work.

Thus arose the type of stratified drift variously known as *overwash plains*, *morainic plains*, and *morainic aprons*. These overwash plains are sometimes found with a width of several miles. Like the valley trains, they are topographically and genetically distinct, and their relations are well known. They have been abundantly described in the literature of glacial geology, and it is, therefore, not needful that more be said concerning them at this point.[1]

Overwash plains may sometimes depart from planeness by taking on some measure of undulation, of the sag and swell (kame) type, especially near their iceward edges. The same is often true of the heads of valley trains. The heads of valley trains and the inner edges of overwash plains, it is to be noted, occupy the general position in which kames are likely to be formed, and the undulations which often affect these parts of the trains and plains, respectively, are probably to be attributed to the influence of the ice itself. Valley trains and overwash plains, therefore, at their upper ends and edges respectively, may take on some of the features of kames. Indeed, either may head in a kame area.[2]

Occasionally a morainic apron, or stratified drift in the general position of a moraine apron, is affected by numerous sags without corresponding elevations. This topographic type has

[1] This type is described in the following places, among many others:

CHAMBERLIN, 3d Ann. Report U. S. Geol. Surv., p. 303; JOURNAL OF GEOLOGY, Vol. II, p. 533. SALISBURY, Ann. Report of the State Geologist of New Jersey, 1892. p. 97.

[2] SALISBURY, Ann. Report of State Geologist of New Jersey, 1892, p. 94.

received the name of *pitted plain*. The sags, in many cases at least, appear to be intimately connected with the ice edge, and so to be marginal phenomena.

Not only may morainic plains and valley trains grade into kame areas at their heads, but they may grade into each other. A wide valley train and a narrow overwash plain may closely simulate each other, and in individual cases it is not easy to say whether the deposits are more properly referred to the one or the other of the two classes.[1] This is especially true where an overwash plain is developed in a valley.

At many points near the edge of the ice during its maximum stage of advance, there probably issued small quantities of water not in the form of well-defined streams, bearing small quantities of detritus. These small quantities of water, with their correspondingly small loads, were unable to develop considerable plains of stratified drift, but produced small patches instead. Such patches have received no special designation.

When the waters issuing from the edge of the ice were sluggish, whether they were in valleys or not, the materials which they carried and deposited were fine instead of coarse, giving rise to deposits of silt, or clay, instead of sand or gravel.

In the deposition of stratified drift beyond the edge of the ice, the latter was concerned only in so far as its activity helped to supply the water with the necessary materials.

C. Deposits at and beyond the edge of the ice in standing water.— The waters which issued from the edge of the ice sometimes met a different fate. The ice in its advance often moved up river valleys. When at the time of its maximum extension, it filled the lower part of a valley, leaving the upper part free, drainage through the valley stood good chance of being blocked. Where this happened a marginal valley lake was formed. Whenever the ice spread over a land surface sloping toward it, there was the possibility of the development of a lake basin between the ice on one hand, and the land surface on the other. Marginal lakes and ponds arising in these and other

[1] SALISBURY, Annual Report of the State Geologist of New Jersey, 1891, p. 97.

ways, were probably not rare at the time of the maximum extension of the ice, and more or less drainage from the ice must have found its way into them. Wherever this occurred, stratified deposits of drift were made in the lakes, the materials for which were borne into the standing water by the streams which issued from the ice. *Deltas* must have been formed where well-defined streams entered the lakes, and *subaqueous overwash plains*[1] where deltas became continuous by lateral growth. The accumulation of stratified drift along the ice-ward shores of such lakes must have been rapid, because of the abundant supply of detritus. These materials were probably shifted about more or less by waves and shore currents, and some of them may have been widely distributed. Out from the borders of such lakes, fine silts and clays must have been in process of deposition, at the same time that the coarse materials were being laid down nearer shore.

Deposition must have taken place in a similar way along the shores of the sea wherever the ice reached it. The silt, sand, gravel, etc., carried to the sea by running water was either deposited at once, or worked over and transported greater or less distances by waves and littoral currents. Such deposits still remain beneath the sea, unless changes of level have brought them above the surface.

During the maximum extension of an ice-sheet, therefore, there was chance for the development, at its edge or in advance of it, of the following types of stratified drift: (1) kames and kame belts, at the edge of the ice; (2) fluvial plains or valley trains, in virtual contact with the ice at their heads; (3) border plains or overwash plains, in virtual contact with the ice at their upper edges; (4) ill-defined patches of stratified drift, coarse or fine, near the ice; (5) subaqueous overwash plains and deltas, formed either in the sea or lakes at or near the edge of the ice; (6) lacustrine and marine deposits of other sorts, the materials for which were furnished by the waters arising from the ice.

[1] Annual Report of the State Geologist of New Jersey for 1892, p. 99; *ibid.*, 1893, p. 266.

DEPOSITS MADE BY EXTRAGLACIAL WATERS DURING THE RETREAT OF THE ICE.

During the retreat of any ice-sheet, disregarding oscillations of its edge, its margin withdrew step by step from the position of extreme advance to its center. When the process of dissolution was complete, each portion of the territory once covered by the ice, had at some stage in the dissolution, found itself in a marginal position. At all stages in its retreat the waters issuing from the edge of the ice were working in the manner already outlined in the preceding paragraphs. Two points of difference only need to be especially noted. In the first place the deposits made by waters issuing from the retreating ice, were laid down on territory which the ice had occupied, and their subjacent stratum was often glacial drift. So far as this was the case, the stratified drift was super-morainic, not extra-morainic. In the second place the edge of the ice in retreat did not give rise to such sharply marked formations as the edge of the ice which was stationary. The processes which had given rise to valley trains, overwash plains, kames, etc., while the ice edge was stationary, were still in operation, but the line or zone of activity (the edge of the ice) was continually retreating, so that the foregoing types, more or less dependent on a stationary edge, were rarely well developed. As the ice withrew, therefore, it allowed to be spread over the surface it had earlier occupied, many incipient valley trains, overwash plains, and kames, and a multitude of ill-defined patches of stratified drift, thick and thin, coarse and fine. Wherever the ice halted in its retreat these various types stood chance of better development.

Such deposits would not cover all the surface discovered by the ice in its retreat, since the issuing waters, thanks to their great mobility, concentrated their activities along those lines which favored their motion. Nevertheless the aggregate area of the deposits made by water outside the ice as it retreated, was great.

It is to be noted that it was not streams alone which were operative as the ice retreated. As its edge withdrew, lakes and

ponds were continually being drained, as their outlets, hitherto choked by the ice, were opened, while others were coming into existence as the depressions in the surface just freed from ice, filled with water. Lacustrine deposits at the edge of the ice during its retreat were in all essential respects identical with those made in similar situations during its maximum extension.

Disregarding oscillations of the ice edge at these stages, the deposits made by extraglacial waters during the maximum extension of an ice-sheet, and during its retreat, were always left at the surface, so far as the work of that ice-sheet was concerned. The stratified drift laid down by extraglacial waters in these stages of the last ice-sheet which affected any region of our continent still remain at the surface in much the condition in which they were deposited, except for the erosion they have since suffered. It is because of their position at the surface that the deposits referable to these stages of the last ice-sheet of any given region have received most attention and are therefore most familiar.

DEPOSITS MADE BY EXTRAGLACIAL WATERS DURING THE ADVANCE OF THE ICE.

During the advance of an ice-sheet, if its edge forged steadily forward, the waters issuing from it, and flowing beyond, were effecting similar results. They were starting valley trains, overwash plains, kames, and small ill-defined patches of stratified drift which the ice did not allow them to complete, before pushing over them, and shoving forward the zone of activity of extraglacial waters. Unlike the deposits made by the waters of the retreating ice, those made by the waters of the advancing ice were laid down on territory which had not been glaciated, or at least not by the ice-sheet concerned in their deposition. If the ice halted in its advance, there was at such time and place opportunity for the better development of extraglacial stratified drift.

Lakes as well as streams were concerned in the making of stratified beds of drift, during the advance of the ice. Mar-

ginal lakes were extinguished by having their basins filled with the advancing ice, which displaced the water. But new ones were formed, on the whole, as rapidly as their predecessors became extinct, so that lacustrine deposits were making at intervals along the margin of the advancing ice.

Deposits made in advance of a growing ice-sheet, by waters issuing from it, were subsequently overridden by the ice, to the limit of its advance, and in the process, suffered destruction, modification, or burial, in whole or in part, so that now they rarely appear at the surface.

DEPOSITS MADE BY SUBGLACIAL STREAMS.

Before their issuance from beneath the ice, subglacial waters were not idle. Their activity was sometimes erosive, and at such times stratified deposits were not made. But where the subglacial streams found themselves overloaded, as seems frequently to have been the case, they made deposits along their lines of flow. Where such waters were not confined to definite channels, their deposits probably took on the form of irregular patches of silt, sand, or gravel; but where depositing streams were confined to definite channels, their deposits were correspondingly concentrated. When subglacial streams were confined to definite channels, the same may have been constant in position, or may have shifted more or less from side to side. Where the latter happened there was a tendency to the development of a belt or strip of stratified drift having a width equal to the extent of the lateral migrations of the under-ice stream. Where the channel of the subglacial stream remained fixed in position, the deposition was more concentrated, and the bed was built up. If the stream held its course for a long period of time, the measure of building may have been considerable. In so far as these channel deposits were made near the edge of the ice, during the time of its maximum extension or retreat they were likely to remain undisturbed during its melting. The aggraded channels then came to stand out as ridges. These ridges of gravel and sand are known as *osars* or *eskers*. It is not to be inferred that

eskers never originated in other ways, but it seems clear that this is one method, and perhaps the principal one, by which they came into existence. Eskers early attracted attention, partly because they are relatively rare, and partly because they are often rather striking topographic features. Their characteristics are well known and will not be recounted here.[1] The essential conditions, therefore, for their formation, so far as they are the product of subglacial drainage, are (1) the confining of the subglacial streams to definite channels, and (2) a sufficient supply of detritus.

Subglacial deposits of stratified drift were sometimes made on unstratified drift (till) already deposited by the ice before the location of the stream, and sometimes on the rock surfaces on which no covering of glacier drift had been spread.

It is to be kept in mind that subglacial drainage was operative during the advance of an ice-sheet, during its maximum extension, and during its retreat, and that during all these stages it was effecting its appropriate results. It will be readily seen, however, that all deposits made by subglacial waters, were subject to modification or destruction or burial, through the agency of the ice, and that those made during the advance of the ice were less likely to escape, than those made during its maximum extension or retreat.

DEPOSITS OF SUPERGLACIAL AND ENGLACIAL STREAMS.

Superglacial and englacial streams might be supposed to make deposits in their channels. It has even been conceived that this

[1] Eskers or osars are described and discussed in the following places, often under the name of kames or serpentine kames: CHAMBERLIN, 3d Ann. Report U. S. Geol. Surv., p. 299; Compte-Rendu, 5th Session of the International Congress of Geologists; JOURNAL OF GEOLOGY, Vol. I, p. 255; *Ibid.*, Vol. II, p. 529. STONE, Proc. Bost. Soc. Nat. Hist., Vol. XX, pp. 430–69. UPHAM, Geol. of N. Hampshire, Vol. III, (under kames); Proc. A. A. A. S., Vol. XXV, p. 216; Report Minn. Geol. Survey, Vol. I, p. 545; Am. Jour. Sci., Vol. CXIV (1877), p. 459, SHALER, Proc. Bost. Soc. Nat. Hist., Vol. XXIII, p. 36; 7th Ann. Report U. S. Geol. Surv., p. 314; 9th Ann. Report U. S. Geol. Surv., p. 549. DAVIS, Proc. Bost. Soc. Nat. Hist., Vol. XXV, p. 477–492. GEIKIE, Great Ice Age, 3d edition, Chap. XIV. HOLST, Am. Nat., Vol. XXII, pp. 590–711. SALISBURY, Ann. Rep. State Geologist of New Jersey, 1892, pp. 41, 79.

was the principal mode of origin of eskers. Against this view, and against the view that superglacial stream deposits are of consequence quantitatively, stand two facts. (1) So far as known the surfaces of ice-sheets are free from drift (apart from wind-blown dust) except for a fraction (and generally a small one) of a mile from their edges; and (2) superglacial streams are in general much too swift to deposit drift, or to allow it to accumulate in their channels. The channels of most superglacial streams in North Greenland, *even near the edge of the ice where surface débris is abundant*, are absolutely free from drift. Judging from the force with which they issue from the ice, englacial streams are likewise much too swift to allow of deposition along their channels, as a general rule.

Such trivial accumulations of drift as may be made in superglacial or englacial channels would ultimately reach the land surface. During the advance of the ice they would be delivered onto the land, as the ice which sustained them moved forward into the zone of melting. They would then be overridden by its further forward motion. During the retreat of the ice, such deposits, once they reached the land surface, would not be subsequently destroyed or overridden by it.

Summary.—Such are the main phases of water action in connection with a single ice-sheet, on the assumption that the edge of the same did not oscillate backward and forward during the period of its advance or retreat. Were this the complete history of an ice-sheet, the stratified deposits, as they now exist, would be (1) in part extraglacial—those made by waters beyond the extreme advance of the ice; (2) in part supermorainic (super-till)—especially those made by extraglacial waters during the retreat of the ice; and (3) in part submorainic (sub-till)—chiefly those made by extraglacial waters during the advance of the ice, and subsequently buried. The actual relations of the stratified drift to the unstratified are, however, far less simple.

RELATION OF STRATIFIED TO UNSTRATIFIED DRIFT.

Deposits made by extraglacial waters during the advance of the ice, edge not oscillating.—At all stages of the glacial period,

extraglacial streams were depositing gravel, sand, or silt in the valleys through which they flowed. Wherever the ice halted temporarily in its advance, valley trains of greater or less extent may have been developed. All those valley deposits which were made during the first advance of the ice were made on territory which was free from glacial drift. Subsequently the glacier ice overrode them in whole or in part, often burying them beneath its own moraine deposits (till). So too, during the first advance of the ice, the waters which did not concentrate themselves in valleys as they issued from the edge of the ice, made deposits in the form or in the position of overwash plains of gravel, sand, or silt. Well developed overwash plains may have been built up before the ice reached its maximum extension, wherever the ice edge stood for a sufficiently long interval of time in a favorable topographic position. Such overwash plains as were developed during the first advance of the ice, lay upon territory which the ice had never invaded, and constitute, if they still remain, the lowest member of the drift series. Subsequently, in its further advance, the ice overrode these deposits sometimes destroying them and sometimes burying them beneath deposits strictly glacial.

It was not simply by extraglacial streams that stratified drift was deposited during the advance of the ice. The marginal lakes which came into existence during the advance of the ice, and there were many, likewise gave rise to stratified deposits of glacio-lacustrine origin. So far as these were formed upon territory which was free from drift, and subsequently overridden by the ice, they were likely to be buried so far as not destroyed. Deposits formed in the margins of seas at the edge of the ice would be subject to the same changes as those formed in lakes, in so far as they were subsequently overridden by the ice.

Still supposing the edge of the ice not to have oscillated, all the deposits of extraglacial waters made during its first advance, whether of the valley-train, overwash plain, lacustrine or other types, were liable to destruction by the further progress of the ice. So far as they were not destroyed they were liable to bur-

ial beneath unstratified drift deposited by the ice itself. So far as not destroyed, therefore, the exisiting deposits of stratified drift made during the first advance of the ice are likely to occupy the basal position (submorainic) in the drift series, in all the territory subsequently overspread by the ice.

Effect of edge oscillation.—Hitherto the assumptions have been made, for the sake of simplicity, that the advancing edge of the ice forged steadily forward, and that the retreating edge was subject to no temporary advances. It is probable that neither of these assumptions is true. It is believed rather that the advance of the ice was interrupted by many minor oscillations of its edge, both seasonal and periodic, though the sum of the advances was greater than the sum of the retreats during any given epoch, up to the time when the ice reached its greatest extension. When the ice advanced to a certain line, and then receded temporarily, incipient overwash plains, or valley trains, or lacustrine beds, or ill-defined patches of gravel and sand, were doubtless deposited on the territory from which the ice had temporarily receded. The gravel and sand in this case would in general lie, not on a driftless bed, but over deposits made by the ice before its temporary recession. The subsequent advance of the ice would be likely to bury these deposits of stratified drift so far as it did not destroy them. Thus by oscillations of the edge of the ice during the general period of its advance, stratified sand and gravel may have come to be enclosed between beds of till. The extent of the area where this sort of action might take place at any one time would depend upon the amount of oscillation which the ice underwent during its advance. But it may have taken place at many times and places and at many stages in the development of an ice-sheet, so that the interbedding of the two types of drift by this process may have been considerable, in the aggregate, during the advance of the ice.

Deposits made by extraglacial waters during the retreat of the ice.—Stratified deposits made by extraglacial streams during the retreat of the ice of any epoch would remain at the surface

(supermorainic) so far as the ice of that epoch was concerned, except in so far as forward oscillatory movements intervened in the general period of retreat. So far as such movements intervened, their tendency would be to bury or destroy such stratified deposits as were overridden by the temporary advances of the ice, making them intermorainic (inter-till). In a complex body of drift deposited by a single ice-sheet, the edge of which was subject to oscillation, it would not always be possible to tell which beds of intermorainic stratified drift were deposited during the advance of the ice and which during the retreat, though the latter would of course overlie the former.

Deposits made by streams as they issued from the ice. — When streams issued from beneath the ice they often made very considerable deposits at the point of issue (kames, alluvial fans, etc.). In case of simple (without oscillation) advance or retreat of the ice, deposits of this sort made during the maximum extension of the ice and during its retreat would remain undestroyed and unburied so far as ice of that epoch is concerned. Those made by the ice at the time of its maximum extension might rest on a driftless surface or on extraglacial stratified drift deposited in advance of the ice, while those made during its retreat would be likely to lie on till.

The deposits made in this position during the first advance of the ice over any region, were likewise liable to rest on driftless surfaces or on stratified drift deposited in advance of the ice itself. The advance of the ice was likely to destroy them in whole or in part, and bury what escaped destruction. Stratified deposits made at the margin of an advancing ice-sheet the edge of which was not oscillating are therefore likely to occupy a submorainic position, to the limit of ice advance.

In case the edge of the ice oscillated during its advance, the kame deposits made during a recessional phase of an oscillation might rest on the till of the preceding advance phase. Likewise the stratified deposits at the edge of the ice during its retreat, commonly, but not universally, rested on till. Marginal deposits of stratified drift made during a recessional phase

of an oscillating movement during the general retreat, were liable to destruction or burial by the next advance phase. So far as buried, they commonly assumed an inter-till position. Those made during the general recession were of course more liable to escape destruction than those made during the advance.

Deposits made by subglacial streams.—Subglacial streams, as well as extraglacial, made more or less extensive deposits of stratified drift. These were sometimes concentrated along sharply limited channels (eskers), and sometimes more widely spread. They were sometimes made on the rock surface below all drift, but more commonly on unstratified drift (till) which the ice had already deposited. Because of the ever-changing conditions at the bottom of moving ice, it is probable that the ice frequently came to occupy beds which streams had temporarily commanded. Wherever this happened, the stratified deposits were likely to be destroyed in whole or in part, or buried. In the latter case they became intermorainic, if they rested upon till, or submorainic, if on rock. It is believed that very large numbers of beds of stratified drift, of limited extent, became in this way interbedded with till. Subglacial waters which did not organize themselves into regular systems of drainage, must have done a similar work on a smaller scale.

Deposits made beneath the ice during its maximum extension in any epoch, and especially near its edge, stood less chance of being buried by later glacial deposits. Stratified deposits made beneath the ice during its retreat, and especially those made near its edge at any stage, were still less likely to attain an inter-till position.

Deposits made by superglacial and englacial streams.—Theoretically, superglacial streams likewise may have made deposits of stratified drift on the ice or in ice valleys. Practically such deposits were probably not made except near the edge of the ice, for nowhere else was there superglacial drift. Even here they were probably not important. Such accumulations of this sort as were made during the final recession of the ice-sheet were delivered on the land as the ice melted, and should remain

at the surface to the present time, so far as the ice of that epoch was concerned. Such deposits as were made by superglacial streams during the advance of the ice must likewise have been delivered on the land surface, but would have been subsequently destroyed or buried, becoming in the latter case, submorainic. This would be likely to be the fate of all such superglacial gravels as reached the edge of the ice up to the time of its maximum advance.

Streams descending from the surface of the ice into crevasses also must have carried down sand and gravel where such materials existed on the ice. These deposits may have been made on the rock which underlies the drift, or they may have been made on stratified or unstratified drift already deposited. In either case they were liable to be covered by till, thus reaching an inter-till or sub-till position.

Englacial streams probably do little depositing, but it is altogether conceivable that they might accumulate such trivial pockets of sand and gravel as are found not infrequently in the midst of till. The inter-till position would be the result of subsequent burial after the stratified material reached a resting place.

Complexity of relations.— From the foregoing it becomes clear that there are diverse ways by which stratified drift, arising in connection with an ice-sheet, may come to be interbedded with till, when due recognition is made of all the halts and oscillations to which the edge of a continental glacier may have been subject during both its advance and retreat.

It is evident that the stratified drift and the unstratified drift had abundant opportunity to be associated in all relationships and in all degrees of intimacy. It is evident that stratified drift may alternate with unstratified many times in a formation of drift deposited during a single ice epoch. The extent of individual beds of stratified drift, either beneath the till or interbedded with it, may not be great, though their aggregate area and their aggregate volume is very considerable. It is to be borne in mind that the ice, in many places, doubtless destroyed

all the stratified drift deposited in advance on the territory which it occupied later, and that in others it may have left only patches of once extensive sheets. This may help to explain why it so frequently happens that a section of drift at one point shows many layers of stratified drift, while another section close by, of equal depth, and in similar relationships, shows no stratified material whatsoever. It also makes it clear that the interrelations of the two types of drift are, on the whole, less complex than they might have been had all the deposits once made by the ice and its accompanying waters escaped destruction.

After what has been said, it is hardly necessary to add that two beds of till, separated by a bed of stratified drift, do not necessarily represent two distinct glacial epochs.

In any region, which has been affected successively by two or more ice-sheets, the complication of stratified and unstratified drift may be even greater. While the ice of one epoch is likely to destroy in part the deposits of earlier epochs, it is not likely to obliterate them altogether. In some regions, indeed, the full series of one epoch is buried beneath the deposits of a second, as the soil between shows. In addition therefore to the complicated series of stratified and interstratified deposits of a first epoch, the ice of a second developed a full set of its own. A prolonged series of ice epochs might bring about a most complicated set of relations, the complete unraveling of which would be a most arduous task.

In America the exposed portion of the formation made by the ice-sheet which reached the greatest extension — the Kansan[1] — should possess less complex combinations of stratified drift than the drift of the region further north which was affected by two or more ice-sheets. The drift of the region where the Iowan formation is exposed, should present in vertical section, more alternations of stratified and unstratified drift than the Kansan, but less than the drift of the region where the Wisconsin formation occurs, since the drift of this latter region is the product of at least three ice-sheets.

[1] JOURNAL OF GEOLOGY, Vol. III, p. 270 ; The Great Ice Age, GEIKIE, p. 753 *et seq.*

CLASSIFICATION ON THE BASIS OF POSITION.

In general the conditions and relations which theoretically should prevail are those which are actually found.

On the basis of position stratified drift deposits may be classified as follows:

1. *Extraglacial deposits*, made by the waters of any glacial epoch if they flowed and deposited beyond the farthest limit of the ice.

2. *Supermorainic deposits* made chiefly during the final retreat of the ice from the locality where they occur, but sometimes by extraglacial streams or lakes of a much later time. Locally too, stratified deposits of an early stage of a glacial epoch, lying on till, may have failed to be buried by the subsequent passage of the ice over them, and so remain at the surface. In origin, supermorainic deposits were for the most part extraglacial (including marginal), so far as the ice-sheet calling them into existence was concerned. Less commonly they were subglacial, and failed to be covered, and less commonly still superglacial.

3. *The submorainic* (*basal*) *deposits* were made chiefly by extraglacial waters in advance of the first ice which affected the region where they occur. They were subsequently overridden by the ice and buried by its deposits. Submorainic deposits, however, may have arisen in other ways. Subglacial waters may have made deposits of stratified drift on surfaces which had been covered by ice, but not by till, and such deposits may have been subsequently buried. The retreat of an ice-sheet may have left rock surfaces free from till covering, on which the marginal waters of the ice may have made deposits of stratified drift. These may have been subsequently covered by till during a readvance of the ice in the same epoch or in a succeeding one. Still again, till left by one ice-sheet may have been exposed to erosion to such an extent as to have been completely worn away before the next ice advance, so that stratified deposits connected

with a second or later advance may have been made on a driftless surface, and subsequently buried.

4. *Intermorainic stratified drift* may have originated at the outset in all the ways in which supermorainic drift may originate. It may have become intermorainic by being buried in any one of the various ways in which the stratified drift may become submorainic.

ROLLIN D. SALISBURY.

EDITORIAL.

FROM the preliminary list of papers sent out by the Secretary of the Geological Society of America, it would appear that an unusually interesting meeting may be expected at Washington during the coming holidays. The presidential address by Dr. Le Conte on "The Different Kinds of Earth-Crust Movements and Their Causes" will undoubtedly contain much of interest as the mature result of his long thought on the dynamics of the crust, and this will be expressed in his usual felicitous style.

It is always interesting to note the distribution of the subjects of the papers of so representative a body. Of the forty-two titles announced in the preliminary list, nine may be grouped under the head of areal or local phenomena; nine under the head of physiographic geology, a part of which are discussions of principles and a part of phenomena; eight under glaciology; four under genesis; two under chronology; two under chemical geology; one under palæontology, and one under correlation. This grouping is not, of course, exact, since many of the papers admit of classification under different heads. There is a notable scantiness of papers on petrography, which has usually been so prominent a feature of the Society programme. Doubtless this will be changed in the final list. As a whole, the synopses of the papers indicate matter of more than usual importance, and show a gratifying activity on the part of the members of the Society.

T. C. C.

REVIEWS.

Elements of Geology, a Text-Book for Colleges and for the General Reader. By JOSEPH LE CONTE. Fourth edition, revised and enlarged, with new plates and illustrations. D. Appleton and Company. 1896.

The many excellences of this admirable text-book are too well known and too highly appreciated to need recital in detail. The author has endeavored to select those phases of geology which are most interesting to students and to general readers, and in this he has attained a rare success. In the interest of a clear exposition he has sought to eliminate unnecessary details, and at the same time to set forth the main grounds on which conclusions are drawn. An infallible judgment in so difficult a discrimination is not to be expected. Few who have made the attempt have succeeded better, on the whole, than has Dr. Le Conte. The style of presentation is easy, graceful and lucid. A philosophical tone pervades the book, and the student is never left long without a reminder of the intellectual processes by which conclusions are reached, or, at least, may be reached, for the reasoning, it must be remarked, savors somewhat more of the office than of the field, but the methods of the latter do not lend themselves equally well to easy and brief statement.

Somewhat more than half the book is occupied with dynamical and structural geology, and the rest with historical. The latter could probably be wisely extended at the expense of the former, and some of the dynamical and structural factors could perhaps be treated to advantage in a historical form. For the average student we think the history of the earth and the history of its typical features, treated causally, are more valuable than an analytical exposition of agencies and structures. Geology is essentially a science of the earth as an organism, and the biography of that organism is its most vital aspect as a factor in general education.

The special topics which have received fresh discussion in this revision of the work are earthquakes, the differentiation of rock mag-

mas, the Cambrian, the structure and affinities of trilobites, of Mesozoic reptiles, and of Mesozoic and Tertiary mammals, and the causes of glacial and other geological climates. Earthquakes are treated in a relatively elaborate way, which is perhaps warranted by the popular interest they awaken. They are, however, given more space than rivers, which have incomparably greater geological and educational importance. It would, we believe, have been better to bring the treatment of rivers and of topographic evolution well up to date even at the expense of a reduction of the space previously given to earthquakes, and to other less universal phenomena. The brief statement of magmatic differentiation, the greater emphasis placed on the Cambrian, and the later results of research on the trilobites, reptiles and mammals are all welcome additions. Much less, we fear, can be said in commendation of the discussion of glacial phenomena. The opening statement (p. 568) relative to the great oscillations of the earth's crust, and especially the unqualified assertion that "the glacial epoch is characterized by an *upward* movement of the crust in high-latitude regions, until the continents in those regions stood 1000 to 3000 feet above their present height," appears to the reviewer to need revision; at least, the student and the general reader should be informed that this once current doctrine has been cast aside by many of the most experienced glacialists on both sides of the Atlantic. That there was a very notable elevation in the *Pliocene* period is not doubted, indeed, among its strongest proofs are the very phenomena appealed to in proof of elevation in the glacial period. Unless the modern science of geomorphy goes for naught, the elevation that produced the fjords and the ragged borders of the northern coasts took place very much anterior to the glacial period. Concurrent with this evidence there has been gathered within the last few years a great mass of data which indicates that during much of the glacial period only a moderate — indeed, in part, a rather low — altitude prevailed. A conservative author may well be pardoned for not accepting these new doctrines, but scarcely for leaving students in total ignorance of them. A specific error of much significance is the statement, following Hilgard, that the Lafayette sands and gravels contain northern bowlders, and their consequent reference to the glacial period. Crystalline pebbles, presumably of glacial origin, occur in the sands and gravels of the Natchez formation, which bears some resemblance to the Lafayette, because largely derived from it, and hence has

been confounded with it. The Natchez formation, however, lies unconformably on the Lafayette, as the writer has demonstrated. The contact shows that the Lafayette had acquired its peculiar ferrugination and partial induration and had been deeply eroded, before the Natchez formation was deposited. The latter holds pebbles of the brick-red, semi-indurated sand of the former in its unconformable layers at the contact. The Lafayette sands and gravels are wholly removed from genetic connection with the glacial series, and the inferences from their "torrential" character should be entirely dismissed. The extraordinary fact about the lower Mississippi valley is the *scantiness* of glaciō-fluvial deposits of a coarse nature.

The term Champlain is not unlike charity in its mantling function, and the pall of the latter is usually much needed in reviewing anything that goes under the caption of the former. Strictly applied to the marine deposits of the Champlain valley and their chronological equivalents, it serves a useful purpose, but when it is made to cover not only these, but the deposits of several different stages of the glacial epoch, its utility is of the inverted order. There is some slight mitigation of these "inherited blunders," to use the expressive phrase of Goode, in the work in hand, but only slight. The Champlain epoch is made to include the low altitude deposits without regard to how they may be sandwiched among the glacial stages. The result of this high-altitude, low-altitude mode of classification is a serious misconception of the real nature of the history of the glacial period.

The weakest points in the book are found in the treatment of the two ends of the geological column, the pre-Cambrian, which is very scantily treated, and the post-Pliocene which largely neglects the investigations of the last decade.

In the discussion of the antiquity of man in America, the doubtful nature of the evidences associated with the auriferous gravels of California are judiciously stated, but the more distant eastern relics are treated with less reserve. The Babbitt find at Little Falls, Minn., is cited as a "good example" of these, and perhaps it is a good example, as the canons of good science were quite ignored in giving it to the public, and the reference of the relics to the same age as the deposition of the beds in the superficial portion and in the talus of which they are found involves a palpable absurdity, as explicitly shown by Holmes. It would seem that students should be taught frankly that the evidence of Quaternary man in America is sharply challenged,

and that, until the trashy portion of the evidence is purged away and solid data are produced, no conclusions can safely be drawn.

These specific criticisms, which have required some little fullness of statement, give disproportion to this review, and it needs correction by a reaffirmation of the very high excellence of the work as a whole.

T. C. CHAMBERLIN.

The Oldest Fossiliferous Beds of the Amazon Region. By FRIEDERICH KATZER, chief of the geological section of the Pará Museum. Boletim do Museu Paraense, Vol. I, No. 4, pp. 436–438. Pará, Brazil, 1896.

It has already been satisfactorily shown that of the Palæozoic series we have in the Amazon valley rocks of Silurian, Devonian, and Carboniferous ages. Whether there is any Cambrian and Permian remains to be determined. The beds below the known Palæozoic rocks are gneisses, crystalline-schists, etc., referred to the Archæan. It is not impossible that some of the quartzites and mica-schists are Cambrian and Lower Silurian.

Upper Silurian beds have been recognized in the Amazon region thus far only at one place, mainly on the Rio Trombetas at Viramundo Falls, where fossils have been found.

In 1895, however, Dr. João Coelho made on the Rio Maecuru a rich collection which has been presented to the Pará Museum. After a careful examination of these rocks, graptolites have been found in them, thus proving the existence of Upper Silurian rocks in the Maecuru valley. This is the first discovery of these fossils in Brazil.

It is worthy of mention, also, that these graptolites were found in beds composed principally of siliceous spicules of sponges. These spicules are visible to the naked eye, but they are better seen with a lens magnifying ten to twenty diameters, or in thin microscopic sections. These sponge remains are the first of the kind found either in the Amazon region or in the Palæozoic beds of Brazil.

The author has recently presented a memoir on the geology of the Amazon, and especially on the Archæan rocks, to the Academy of Bohemia, based on his studies of a series of specimens from the zone north of Alemquer, and of another set brought by Dr. Goeldi from his scientific expedition to Guiana in 1895. In an early number of this Boletim he will give a résumé of that paper.

One of the chapters of the paper is on the Devonian rocks. From the Devonian beds on the Rio Maecuro Dr. João Coelho brought a large number of fossils, which show the existence of beds literally full of mollusks, principally brachiopods, proving the existence of members of the Devonian series more recent than has been supposed to exist there.

The study of these materials shows the necessity of a study of the stratigraphy of the Amazon region in order to fix the position of these fossiliferous beds and to settle finally the geologic structure of this part of South America. It will be the first important task of the geological section of the Pará Museum to give a correct synopsis of these structural features. J. C. BRANNER.

The Formation of the Quaternary Deposits of Missouri. By JAMES E. TODD. Reports of the Missouri Geological Survey, Vol. X. State Printer, Jefferson City, 1896.

This excellent report describes in detail the glacial drift which covers the northern portion of Missouri, treating of it analytically in its various phases, including the forest beds and old soils that are embraced within the drift. This is followed by a description of the loess and its associated deposits; of the terraces and ancient channels, and of the alluvial deposits of the existing streams. Following this exposition of the observed facts, the leading problems that arise from them are taken up and considered in succession. Under this head is discussed the former existence of a barrier between the Missouri and Gasconade rivers, which the author regards as an important factor in explaining the phenomena above that point. The origin of the loess is considered and the conclusion reached that it had a fluvio-lacustrine origin. In considering the erosion of the Missouri River, it is concluded that it had unusual facilities for rapid excavation of its channel. A postglacial deformation of the Pleistocene plain is advocated. The method of deposition of the drift is discussed and some modifications of the simple glacial hypothesis suggested. The recent classification of the drift sheets is adopted. The report is closed by a brief, clear sketch of the sequence of events. The discussion is careful and judicial in tone. The report is well illustrated with photographic views and profiles and the necessary maps. T. C. C.

Der Eläolithsyenit der Serra de Monchique, seine Gang- und Contactgesteine. By K. v. KRAATZ-KOSCHLAN and V. HACKMAN. Tschermak's Mineralogische und Petrographische Mittheilungen, Vol. XVI, pp. 197–307, Pls. IV and V. 1896.

The rock making up the mass of the Serra de Monchique in the southern part of Portugal, first described as "granite" by Bonnet in 1850, was later recognized as a new type by Blum in 1861, and by him given the name *foyäite*, from the dominant peak of the range. It is today known as the foyäite type of the elæolite syenites. The present paper, while largely taken up by detailed petrographic descriptions, is professedly a study of the geological relations of the various rocks.

The elæolite syenite *massif* is roughly elliptical in area, with its longer axis, 15.5 kilometers, extending nearly east and west. Its breadth is about 5.5 kilometers. It consists essentially of two main mountain ridges, separated by the northeast and southwest valley in which the village of Monchique lies. The more easterly of these two ridges takes its name of the Picota from its dominant peak (774 meters), while Mount Foia (902 meters) lends its name to the western ridge. The whole elliptical area is enclosed by the shales and sandstones of the Culm, and the intrusion probably took place within Carboniferous time.

A zone of contact metamorphism was traced around a large portion of the area, and is assumed to completely surround it. Near the contact the normal syenite becomes finer grained, and is either a mica-foyäite, in which the non-micaceous dark minerals have almost disappeared, or has the usual ægirine-augite replaced by ægirine. These changes are accompanied by the addition of låvenite, spinel, and tourmaline. The surrounding metamorphosed sediments consist of altered quartzose *grauwacke*, black *hornfels*, and *knotenthonschiefer*. A cordierite-mica-hornfels which occurs as an inclusion in the elæolite syenite is regarded as an altered diabase. So-called "diabase hornfels" occurs in two places in the metamorphic girdle and is assigned a similar origin. The width of the contact zone varies from a few meters to over a hundred meters, but is in general not so wide as would have been expected in the case of an intrusive granite mass of equal size. It is considered that the alteration was conditioned by the temperature of the eruptive mass and not, to any great extent, to pneumatolytic processes.

Numerous dikes cut the syenite massif but have not been traced

into the surrounding sedimentary rocks. Their strike is generally north and south, northeast and southwest, and northwest and southeast. Only one was noticed with an east and west strike, and their course is accordingly frequently nearly at right angles to the trend of the mountains. They are most commonly from one-half to one meter in width, the monchiquites being particularly variable. As a whole they form a series of differentiated rocks genetically related to the main elæolite syenite. The observed types are: bostonite-porphyry, tinguaite, nepheline-syenite-porphyry, camptonitic tinguaite, and camptonitic and monchiquitic rocks.

The petrography of all the rocks mentioned has been worked out with considerable detail, and is accompanied by several chemical analyses, forming a valuable contribution to the literature of these interesting types. It is shown that the nepheline-syenite of the Foia is poorer in the nepheline than the rock of the Picota, and closely resembles the pulaskite of Arkansas. It presents many features which point to a quicker solidification at less depth than is indicated in the case of the Picota facies. The study of the dike rocks brings out many interesting and suggestive points which can only be referred to in a brief review. With the suggestions embodied in Pirsson's recent paper[1] on the analcite series of rocks in mind, the rôle played by that mineral in these Portuguese rocks, and the description of a so-called "leucite-tinguaite-vitrophyre" with its high alkali contents and devitrified glassy base, become doubly interesting.

The microscopic petrography of the altered sediments is minutely described, and the paper ends with an excellent summary, in which the general sequence of the intrusive activities is presented. The plutonic mass of the Picota, slowly cooled at great depth, is the oldest portion of the *massif*, and probably also underlies the rock of the Foia, which is regarded as an already somewhat differentiated, more acid, upper portion, which solidified nearer the original periphery of the mass. Certain *schliere* in the Picota area are similar to the rock of the Foia. Corresponding to these more acid differentiation products, are the tinguaite dikes, as later intrusions or *Nachschübe*. Basic differentiation products are represented by slowly cooled theralitic rocks (essexite and teschenite), and their corresponding dikes of the camptonite-monchiquite series. These rocks are thought to be younger than the tinguaites, but no satisfactory evidence was obtained

[1] This JOURNAL, Vol. IV, p. 679.

on this point. The youngest intrusion of all is represented by the leucite-tinguaite-vitrophyre.

It is to be noted that the process of differentiation here described, inasmuch as the more acid facies of the elæolite syenite occur on the periphery of the mass, differs from those described by Brögger, in which the more basic constituents have tended to migrate toward the cooling surface. This difference, coupled with the fact that the authors refer only once, very casually, to the whole intruded *massif* as a laccolite, gives cause for regret that they were not able to devote more time to the study of field relationships than was actually at their disposal.

F. L. RANSOME.

Geological Survey of Canada. G. M. DAWSON, Director. *Ann. Rept. U. S.*, Vol. VII, 1894. Ottawa, 1896.

The summary report of operations is followed by a report on the area of the Kamloops map-sheet by Dr. G. M. Dawson, a report of an exploration of the Finlay and Oomenica rivers by R. G. McConnell, a report upon the country in the vicinity of Red Lake and part of Berens River, Keewatin, by D. B. Dowling, a report upon a portion of the eastern part of Quebec, by R. W. Ells, with a chapter upon the Laurentian north of the St. Lawrence, by F. D. Adams, a report upon the surface geology of portions of New Brunswick, Nova Scotia, and Prince Edward Island, by R. Chalmers, and the usual statistical tables and notes on the analyses and collections made.

Within the year an important change in the management of the survey occurred, Dr. A. R. C. Selwyn, who had served as director since the retirement of Sir W. E. Logan in 1869, being granted leave of absence and the following January receiving superannuation. Dr. G. M. Dawson, his successor, was recalled from the field early in October and has since been in charge of the work. Twelve parties were in the field. Dr. Dawson himself spent some time in the Kamloops and adjoining regions investigating recent mining developments. In the Cariboo mining districts the study of the changes in drainage consequent upon glacial conditions was undertaken as likely to yield important results as to the distribution of the auriferous river gravels. The history of these gravels and their association with the glacial beds is traced in detail in the Kamloops report. Mr. R. G. McConnell spent the season in the foot-hills of western Alberta and in the south-

ern part of the west Kootanie district. Mr. J. B. Tyrrell conducted an expedition through the "Barren Grounds," but owing to the short time which elapsed between his return and the publication of the report, only brief notes on the trip are given. A somewhat fuller account of the expedition of 1893 is, however, inserted. Dr. R. Bell and Mr. W. McInnes spent the season in Ontario on work previously begun. Among other points, Dr. Bell determined that the gneissic area between St. Mary's River and Gonlis Bay is not connected with the granitic tract lying to the northeast, but forms an isolated mass. Dr. R. W. Ells was engaged upon work along the Upper Ottawa and adjacent regions. Some interesting points of structure were observed at various places. While it is very evident that the syenites or granites, as a whole, in this section are intrusive in the crystalline limestone, some portions of them are of comparatively recent date. At one point they have disturbed horizontal beds of Calciferous and Chazy, and at another have penetrated and altered the Potsdam. Mr. A. P. Low spent the seasons of 1893–4 in exploring the interior of Labrador and his report, when it shall be completed, promises to correct the popular notion that Labrador Peninsula is a waste, barren region totally unfit for habitation. One of the important results of the exploration is the discovery of a great tract of Cambrian rocks carrying rich beds of iron ore. The striæ of the region show that the ice of the glacial period flowed off in all directions from the central area. Mr. R. Chalmers concludes as a result of the season's work that the facts altogether demonstrate that Nova Scotia has been glaciated entirely by ice which gathered upon its own surface, and afford no evidence of a great ice-sheet crossing the Bay of Fundy and overriding that peninsula. Mr. Whiteaves reports that the second part of the third volume of *Palæozoic Fossils*, consisting of a monograph upon the fossils of the Guelph formation of Ontario, is completed and ready for publication.

The volume as a whole is well printed and well illustrated and forms a most valuable addition to the literature of the region. The area in which the Canadian Survey works is not only one of great extent, but also of great complexity. It is furthermore to a considerable extent unsettled and unexplored. As a result, the cost of geological investigation is relatively high. In view of these facts, and the known wealth in mineral resources of much of the partially explored country, it would seem that the director's plea for larger appropriations is well founded. It is to be hoped that the government

will find itself able to rapidly expand the work and give the new director adequate means for the remarkable opportunities for investigation which the region affords. H. F. Bain.

Proceedings of the Indiana Academy of Science, 1895; Geological Subjects.

Six papers on purely geological topics were read before the Indiana Academy during the year, besides a number of others of more or less interest and value to geologists. The most important geological paper of which an abstract is published is that by A. H. Purdue upon the Charleston, Missouri, earthquake of October 13, 1895. The shock or shocks of that earthquake were of sufficient force to break plate glass windows, crack brick walls, and to throw down brick chimneys at several places, and it seems to have been felt over an area of more than 400,000 square miles. The author might have called attention to the fact that within the area affected there are a score or more of colleges and universities at which geology is taught, but that not one of these institutions had a seismograph or seismoscope in working order, and that there were therefore no accurate observations made upon the time or nature of the shocks.

In "Some Minor Eroding Agencies," by J. T. Scovell, attention is directed especially to the work of burrowing animals: ground hogs, gophers, badgers, prairie dogs, cray fishes, and burrowing insects of various kinds. When Mr. Darwin mentioned the geologic importance of earthworms it was generally thought that he was making the most of a very small affair, but when his data were completed every one was amazed to find the results so important. Mr. Scovell's points are doubtless well taken, but if he will make and record his observations in such a manner as to give them a *quantitative* value, he will do the science of geology an excellent service. In some instances this is impossible, but in others it is not.

It is cause for congratulation that the legislature of the state of Indiana recognizes the importance of coöperating with the State Academy of Science. Show us a state in which the legislature and the people demand of the scientific men scientific results, regardless of whether they have immediate "practical" value and we will show you a state that contributes its full share to the advancement of science and of civilization. J. C. B.

Areal Geology of Missouri (Mo. Geol. Surv., Vol. IX, sheets 1–4, 412 pp., 4 folio topographic and geologic maps, 24 plates, 53 figures. Jefferson City, 1896.)

The volume includes four sheet reports: (1) Higginsville, 1892; (2) Brevier, 1894; (3) Iron Mountain, 1894; (4) Mine La Motte, 1896. These reports were issued as independent reports for separate distribution, but for library uses are bound together in a single volume uniform in style and size with the remaining volumes issued by the present survey. H. F. B.

Om kvartära nivåförändringar vid Finska viken (On Quaternary Changes of Level near the Bay of Finland). By GERARD DE GEER. Sveriges geologiska undersökning Afhandlingar och uppsatser; No. 141, pp. 17. Stockholm, 1894.

The author gives an account of some observations in 1893 on the east coast of the Baltic. By studies in the field and by an examination of the topographic charts made by the Russian government three ancient shore lines were traced, extending around the east end of the Bay of Finland and southward close to the German boundary. The highest of these are referred to the "*late-glacial*" age, the time of recession of the Baltic ice. Northeast from Helsingfors it reaches an elevation of 152 meters above the present level of the bay, but toward the east and south it falls a little below thirty and twenty meters above this level. There are indications that the province of Curland and even Northern Germany were affected by the tilting which deformed this beach. Its position is such that the lakes Peipus, Ladoga, and Onega must have been arms of the Baltic at the time it was made. Another series of terraces marks the Ancylus stage of the Baltic. This maintains an altitude of from 45 per cent. to 50 per cent. of that of the late-glacial beach. A third well-marked beach line is referred to postglacial times. This is the lowest of the three, having an elevation of only four meters above the present level of the bay of St. Petersburg. To the west and north it rises to several times this height. The occurrence of oak and the peccary in deposits inside of this beach is referred to as evidence of a milder climate in an earlier postglacial time. J. A. UDDEN.

Index to Volume IV.

ERRATA

To article on Schistosity and Slaty Cleavage.—Owing to absence from the United States, Mr. Becker had no opportunity of correcting proof of this paper and the following errors crept into the symbolic expressions:

The first sentences and the footnote on page 431 should read as follows: "If horizontal edges of the unit cube are extended in the ratio α, so that these edges in the strained mass have a length α, then the vertical edges are contracted in the ratio $\frac{1}{\alpha}$. It is usual to define the quantity $\alpha - \frac{1}{\alpha}$ as the 'amount' of shear. If the unstrained cube contained a sphere, this in the strained mass would become an ellipsoid with axes α, 1, $\frac{1}{\alpha}$.*

"Since α is greater than unity, and $\frac{1}{\alpha}$ less, ..."

* "If the equation of the sphere is $x^2 + y^2 + z^2 = 1$, and if x_1, y_1, z_1 are the values which the same points have after strain, $x_1 = \alpha x$; $y_1 = \frac{y}{\alpha}$ and $z_1 = z$. Substituting in the equation of the sphere evidently $\frac{x_1^2}{\alpha^2} + \alpha^2 y_1^2 + z_1^2 = 1$ represents the sphere after deformation. The volume of the ellipsoid is $\frac{4}{3}\pi . \frac{1}{\alpha} . \alpha . 1 = \frac{4\pi}{3}$, which is also the volume of the sphere."

On page 432, footnote, for "undisturbed" read "undistorted."

On page 439 the sentence beginning on the eighth line should read thus: "If x, y, z are the initial coördinates, x_1, y_1, z_1 the final coördinates of a point, and b a constant, $x = x_1$; $y = y_1$; $z = z_1 - y_1 b$ represents a scission."

On page 441, footnote, for "$\frac{1}{\alpha}\beta$" read "$\frac{1}{\alpha\beta}$."

On page 444, line 14, for "more" read "mere."

To article on Laccolites in Southeastern Colorado.—On page 818, fourth line from bottom, for "formation" read "deformation."